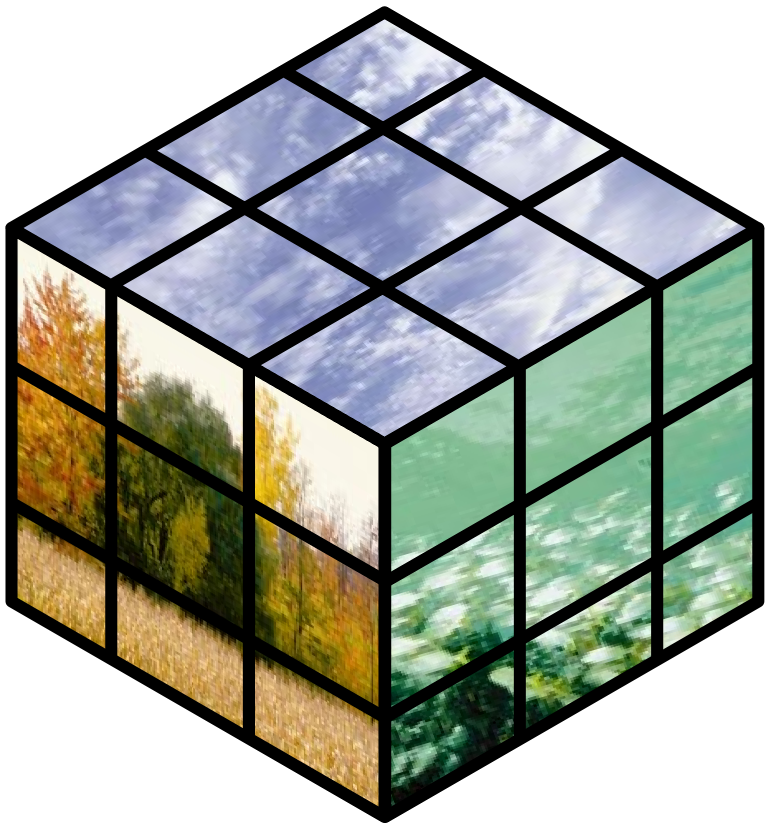
Ecological Research Strategy

Strategic Directions and Priority Research Objectives



Advancing the Science of Ecological Risk Assessment and Risk Management

Office of Research and Development
U.S. Environmental Protection Agency
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F O R E W O R D

"How do we best target society's limited funds to protect ecosystems from irreversible harm so that the efforts and money are not wasted because they are unnecessary or insufficient?"

"*The Tragedy of the Commons*"

Three decades ago, Garrett Hardin told the tale of "The Tragedy of the Commons." In the distant past, villages had "commons," where villagers were allowed to graze their livestock. The benefit to a single farmer from adding a whole animal to the commons was much greater than his fractional loss of production per animal caused by dividing the pasturage among a slightly larger total number of livestock. The "tragedy" struck when overgrazing reduced everyone's production below some floor of profitability and sustainability. The solution was to develop rules that constrained individuals from acting strictly in their own interest, when such behavior was counter to the common good.

We find ourselves today with a more complex, but fundamentally similar problem with our modern commons. Over large regions (e.g., states, multistate watersheds and airsheds, and federal entities such as National Forests and U.S. Environmental Protection Agency Administrative Regions), people agree to limit their freedom to act strictly in their own interest in order to preserve the environment, plants and animals and their associated ecosystems that represent the modern commons. Through combinations of regulations, compacts, public land management decisions, and voluntary efforts by individuals and groups, society seeks to reduce the adverse effect of its daily commerce on the commons so that, over the long term, it continues to provide the goods and services that people value and on which they have come to depend.

Just as in the ancient villages, however, the commons remains necessary for survival, and there is a strong social aversion to restricting the freedom of individuals to act according to their own inclinations, unless such actions clearly harm others or restrict their freedom. And so, society must be careful to exert its efforts, its costs, and its strictures on behalf of the activities that are most likely to preserve and maintain the commons. Whether we are referring to the political capital required to enact a law or to defend an administrative regulation, or to the reduction of profitability to corporations and individuals caused by compliance with environmental regulations, or to the investments by individuals and groups in conservation easements or reclamation efforts, society cannot afford to waste its efforts by pursuing goals that are either unnecessary or insufficient.

What is needed is an approach to assessing the relative importance of the various threats to today's more complex commons, so that modern society's efforts can be directed at those actions that are most likely to succeed over the long run in maintaining the goods, services, and values on which society has come to depend. This requires that all significant threats (which are called *stressors* in ecological risk assessment) to all potentially vulnerable plants, animals, and ecosystems (called *receptors*) be compared objectively and quantitatively, both now and for the foreseeable future. And it is important to consider threats as they act or might be expected to act in concert to exert harm (otherwise, we run the risk of pursuing courses of action that may be necessary but insufficient). To assess these threats, it is necessary to quantify the simultaneous occurrences of stressors and receptors in time and space (called exposure) and then to apply "exposure-response" relationships to predict the degree of harm resulting from the present or future mix of exposure profiles in an area. Because, in ecosystems, local events can exert consequences among adjacent ecosystems, such analysis generally should be conducted over an area large enough to be considered a "region" (e.g., potentially ranging in size from an "ecoregion" to a large, multistate watershed or administrative region). Ultimately, we are concerned about assessing the risk that the overall effects of human activities on ecosystems in such a region will be so great that the system will no longer continue to furnish the goods, services, and values that society has come to expect; by analogy, a modern tragedy of the commons.

This question is the foundation of the Ecological Research Program: How do we best target society's limited funds to protect ecosystems from irreversible harm so that the efforts and money are not wasted because they are unnecessary or insufficient?

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EXECUTIVE SUMMARY

Background

In virtually every major environmental act, congress has required that the U. S. Environmental Protection Agency (EPA) not only ensure that the air is safe to breathe, the water safe to drink, and the food supply free of contamination, but also that it protect the environment. As a result, EPA's Office of Research and Development (ORD) has established research to improve ecosystem risk assessment as one of the seven highest priority research areas for investment over the next 10 years.

To meet the combined requirements of the legislation, it is increasingly clear that scientific solutions to ecological issues can no longer be isolated to one stress, one scale, one level of biological organization, or one media. It also is obvious that because of the complexity of environmental problems and the ecosystems on which they act, environmental problems are not as likely to be solved as they are to be managed. Because not all ecological changes are "bad", ecosystem management becomes more a matter of social tradeoffs among alternative uses, rather than simply a matter of protection.

The goal, therefore, of the Ecological Research Program is to

> "[p]rovide the scientific understanding required to measure, model, maintain and/or restore, at multiple scales, the integrity and sustainability of ecosystems now, and in the future."

In the context of this program, *ecological integrity* is defined in relative terms as "[m]aintenance of ecosystem structure and function characteristic of a reference condition deemed appropriate for its use by society", and *sustainability* is defined as "[t]he ability of an ecosystem to maintain relative ecological integrity into the future."

It is ORD's vision that by 2008, EPA researchers will have developed the next generation of measurements and models necessary to protect the present and probable future sustainability of ecosystems at local, watershed, and regional scales. Obviously, this is not a vision or goal that can be accomplished by ORD alone, but is one that will be dependent on contributions from the in-house and extramural programs, other agencies, the academic community, states, and others. Research within ORD then must be prioritized, capitalizing on the strengths of the organization and the needs of clients most closely supported by it. The following table (Table E-1) provides a summary of the overall structure to the program, considering example scientific questions, tasks, products, and utility to the clients.

Consistent with the recommendations from a recent report from the National Research Council entitled, "Building a Foundation for Sound Environmental Decisions" , the Ecological Research Program proposes to maintain a "core" research program that is applied to the program office's, high-priority needs. The core research ensures that ORD is maintaining the capability EPA needs now and in the future, whereas the program priorities ensure that the core program is applied to the most critical needs.

Because of the demands on ORD from multiple clients, including congress, the public, the scientific community, and the program offices (to mention but a few), organizing ORD's research can be approached from multiple directions driven by these different clients. The structure is not unlike a Rubik's cube, in that, once one has one face structured fully to take full advantage of all the expertise within ORD, the other sides are unlikely to be as consistent in pattern. The research presented in this strategy begins with the core research as the primary face of the strategy and the high-priority needs, as determined by the risk posed, as the secondary axis for organizing the research foci.

Program Objectives

The program is developed around the following four fundamental research areas and objectives.

(1) Monitoring Research—developing indicators, monitoring systems, and designs for measuring the exposures of ecosystems to multiple stressors and the resultant response of ecosystems at local, regional, and national scales.

Table E-1. Summary of major elements of the Ecological Research Program.

Research Topic	Strategic Questions	**Example Tasks**	Example Products	**Uses**
Research to improve ecosystem risk assessment, considering multiple stressors' action on multiple receptors and endpoints at multiple scales	What is the current condition of the environment? What stressors are most significant in affecting the condition? Where are they? How are they distributed? What are the mechanisms of adverse effects? How sensitive are ecosystems to chemical and nonchemical exposures? What is the relative risk posed by stressors, now and in the future? What is the sustainability and vulnerability of ecosystems? What options are available to manage the risk? How best are degraded systems restored?	**Develop indicators of ecological condition** **Evaluate monitoring designs for multiple scales** **Develop multiscale exposure profiles for important stressors** **Conduct cause/effects research at multiple levels of biological organization** **Develop multiple scale, multistressor, multiendpoint relative risk methods** **Conduct ecosystem restoration studies**	National Land Cover Database for all regions and indicators of landscape vulnerability and human stress at watershed and larger scales Suites of new, field-applicable biological indicators/criteria for measuring, understanding, and diagnosing ecosystem exposures and effects. Multimedia, multistress exposure models for defining the distribution of stresses, alone and in combination, at local, watershed, and larger scales Ecosystem models for predicting the response of ecosystems to multiple stressors, at multiple scales Assessment techniques and guidelines for defining ecosystem sensitivity, developing associated exposure profiles, and quantifying ecosystem sustainability Documented techniques for the restoration of valued ecosystems Risk management strategies that take advantage of pollution prevention and the self-purifying potential of natural systems	**To assist stakeholders at local, regional, and national scales, make cost-effective management decisions on the protection of ecological resources by knowing what the most important problems are, how to get the desired result, how to verify/measure that result, and how to improve conditions now and in the future.**

(2) Processes and Modeling Research—developing the models to understand, predict, and assess the current and probable future exposure and response of ecosystems to multiple stressors at multiple scales.
(3) Risk Assessment Research—developing and applying assessment methods, indices, and guidelines for quantifying risk to the sustainability and vulnerability of ecosystems from multiple stressors at multiple scales.
(4) Risk Management and Restoration Research—developing prevention, management, adaptation, and remediation technologies to manage, restore, or rehabilitate ecosystems to achieve local, regional, and national goals.

These four objective areas are consistent with the historical strengths of ORD's research (i.e., the core research of ORD). The specific research issues to which these capabilities are applied are, however, always changing.

In the forefront of improving the ability to make ecosystem management decisions in the future, considering EPA's move to more flexible regulations and decentralized decision making, is more emphasis on the relative risk. Therefore, a better understanding of the impact of multiple stressors, at multiple scales, and at multiple levels of biological organization are underlying factors that run throughout the strategy. Although these are not new areas for research in ORD, the core program will emphasize explicitly research considering these factors over the next 5 to 10 years.

Core Research

It is essential to the long-term responsiveness of ORD to maintain a focused core program that can be applied to the current and future needs of EPA (not unlike the way the trunk of a tree supports its canopy). Using the common goal as a guide there are a number of essential areas of basic research that need to be maintained and will serve as the primary research foci over the next 3 to 5 years.

Of particularly high priority, will be

- monitoring research focused on biological indicator development at molecular, community, and landscape levels of biological organization for multiscale monitoring and ecosystem condition and exposure evaluation, new characterization methods and technologies, and improved, multiscale monitoring designs;
- model development research focused on improving first-principle exposure and effect models, coupling and scaling effects and exposure models, and developing a common modeling framework to improve integration of models;
- risk assessment research focused on developing guidelines, place-based assessment methods, and the conduct of special assessments; and
- risk management and restoration research focused on watershed and larger scale pollution prevention, management, adaptation, remediation, rehabilitation, and restoration technologies for aquatic systems.

Table E-1 provides a summary of the research program questions and example tasks and products.

Monitoring Research

With rare exceptions, ecosystem monitoring has been conducted to meet short-term or program-specific objectives, and it is seldom harmonized or coordinated across large geographic areas. Comparable measurements are taken for only a short time (e.g., less than the length of many natural ecological cycles), across a large area, or when they are made over a long period, and they are usually restricted to one or a few study sites. Recently, however, there has been revived interest in creating a multiagency ecological monitoring network that would monitor the condition of ecosystems and provide periodic "report cards" to the public.

Early experience with EPA's Environmental Monitoring and Assessment Program revealed that there remains a great deal of scientific controversy over what to measure, how to measure it, and with what network design. The emerging consensus, based in large part on the ecological risk assessment paradigm, is that indicators of exposure (i.e., the juxtaposition of a stressor and an ecological receptor in time and space at a comparable and appropriate scale and effect; that is, the actual change in an ecological receptor, again at a number of relevant and appropriate scales in time and space) should be monitored simultaneously. Additionally, environmental characteristics that modify the exposure-effect relationship (i.e., characterization), as well as exposure indicators that signify that an exposure has occurred in the past, perhaps in episodes or cumulatively over long periods of time, also need to be monitored.

Therefore, the core research in this area will include

- developing suites of new, field-applicable, biological indicators and criteria for measuring, understanding, and diagnosing ecosystem exposures, effects, and recovery;
- developing and implementing systems to deliver reliable, timely, and consistent environmental monitoring and measurement information to the public and communities; and
- developing multiscale monitoring designs and statistical techniques for monitoring current conditions and trends in the condition and exposure of the nation's ecological resources.

Modeling and Process Research

Process and modeling research develops the basic understanding and modeling technology to predict future landscapes, stressor patterns, ambient conditions, exposure profiles, habitat suitability, and probable receptor responses as a function of risk management alternatives. Future models will consider multimedia, multipath sources, intermedia pollutant transfers, transport and transformations, micro-environments, and receptor activity patterns in the context of anticipated regional changes resulting from both natural and anthropogenic causes. In order to estimate the distribution of exposure to multiple stressors across vulnerable ecosystems, there is the need to understand and quantify the governing processes and develop models linking sources, transport, and transformations of pollutant stressors, along with physical stressor predictive models, to estimate exposures at appropriate temporal and spatial scales. These models must also be linked to landscape models to characterize future environments and habitats. In addition, ties to appropriate suites of biological response models are essential to the risk manager, as often the goal is to forecast the response of receptors to management actions.

For convenience and simplicity, current models used to predict the outcome of any individual management option are generally single-media models, involving only a single pollutant or stressor. Modeling must move past this piecemeal approach and represent the interactions that occur across scales, media, stressors, and multiple levels of biological organization. The complexity of the problems that EPA will face in the future will require models to predict beyond today's physical and chemical conditions to new, never-before measured conditions. Therefore, future models need to be based as closely as possible on first principles, and they need to be sufficiently complex in their description of the underlying processes such that they become virtual realities. By doing so, scientists can best advance the understanding of the whole of the environment and develop anticipatory and more flexible management strategies that avoid unwanted futures. It is the vision for this area of research that future models will be interrogated as virtual realities in the same way that engineering tables and interactive CD-ROM encyclopedias are used today.

High-priority research will include

- developing a prototype modeling framework for EPA for a full range of computing architectures from personal computers to scalable, parallel machines;
- developing an air modeling system capable of handling multipollutant issues and multifunction interaction;
- understanding, quantifying, and modeling key transport and transformation processes for nutrients, industrial chemicals, pesticides, metals, and radiatively important trace gases and incorporating these processes into terrestrial and aquatic exposure assessment models; and
- developing stressor/response analyses and techniques to establish cause-and-effect relationships and to improve effects models.

Risk Assessment

EPA's Science Advisory Board (SAB) report, titled *Future Risk: Research Strategies for the 1990's*, emphasized the need for a fundamental shift in EPA's approach to environmental protection and challenged ORD to provide leadership in the area of ecosystem science. This report provided the impetus to shift the approach previously used in ecological assessments by focusing on the resources at risk and their composition within landscape, multiple stressor, and multiple assessment endpoints. In 1992, EPA published the Ecological Risk Assessment Framework as the first statement of principles for ecological risk assessment and, in 1996, published the first draft of the Ecological Risk Assessment Guidelines, which describe methods for conducting the more conventional single-species, chemical-based risk assessments; they describe techniques for assessing risk to ecosystems from multiple stressors and from multiple endpoints.

The focus of research in this core research area will be to continue development of better ecosystem risk assessment methods. Specifically, high-priority areas will include

- developing risk assessment guidelines to improve and standardize ecological risk assessments within and outside EPA;
- conducting ecological risk assessments at real places, on special problems, and for important chemicals; and
- developing new methods to conduct place-based, multiple-stressor assessments.

Risk Management and Restoration

Ecosystem management and sustainability recently have moved to the forefront of both scientific and policy debates. Many of the issues raised remain unresolved (including a consensus on the meaning of sustainable ecosystems), but one thing seems clear—the increasing attention to ecosystem management, in tandem with the issue of sustainability, represents a significant reexamination of U.S. land and natural resources management practice and policy. Risk management actions are an important part of ecosystem management and typically occur at multiple scales. For example, transboundary issues, such as acid deposition and atmospheric levels of greenhouse gases, require risk reduction via widespread actions that usually are applied at every source. In most cases, active management- and technology-based risk management (which often follows as an implementation requirement from policies and regulations) typically is applied to watersheds or ecosystems that can be defined by watersheds. Accordingly, the strategic choices for the scales of risk management research are (1) *national*, for regulatory-based transboundary consideration, and (2) *the watershed*, for most regulatory and local management effects.

Given the rate of development of the man-made environment, present regulatory approaches may not always limit risks to tolerable levels for vulnerable ecosystems. There is a need to develop new, cost-effective prevention, control, and remediation approaches for sources of stressors, and adaptation approaches for ecosystems. Ecosystem stressors from both natural and anthropogenic sources are inevitable, and cost-effective stressor reduction, as a means to reduce risks, may not always be feasible or practical. Therefore, it is also important to invest in restoration technologies, including protocols and indicators to diagnose ecosystem restoration needs, evaluate progress toward restoration, and establish ecologically relevant goals and decision support systems for state and community planners and their supporting consultants to facilitate consistent, cost-effective decisions on ecosystem restoration within watersheds.

The research in this core research area will focus on

- developing and verifying improved tools, methodologies, and technologies to improve or maintain ecosystem condition at watershed scales;
- developing best management technologies to reduce the impact of watershed development on the biological and chemical condition of stream quality;
- developing techniques to improve decontamination of stream sediments;
- developing techniques to decrease the risk of degradation through adaptation of the landscape, ecosystems, and species; and
- developing the techniques to restore and rehabilitate ecosystems to achieve local, regional, and national goals.

Specific Environmental Threats

ORD's research budget is structured in relation to the client offices it serves (Air, Water, Pesticides and Toxics, Hazardous Waste, and Multimedia—this last area being the source of much of the funding supporting the core research program). The highest priority environmental threats are where the core capabilities are ultimately focused.

Air Research

None of EPA's air research goals have ecological resources as the primary endpoint of concern. Although there is interest in the exposure and effects of a variety of air pollutants on ecosystems, the primary focus is, and has always been, human health. The Ecological Research Program benefits from the human health goals because the modeling technology, in particular, is of importance as a means to forecast both current and future, large-scale exposures to ecological resources. Several areas of research have, however, been chosen as high-priority issues for investments; one of those is ozone. Adverse effects have been documented for single species of vegetation and are likely to have influence on ecosystems as a whole. Ozone damage to plants is projected to be extensive, with an estimated impact exceeding $1 billion in lost food crops and timber products in the United States every year. Understanding atmospheric ozone formation, model development, and ozone effects research is therefore of the highest priority. The goal of the research will be to develop tropospheric ozone precursor measurements, modeling, source emissions, and control information to guide cost-effective risk management options and to produce health and ecological effects information for National Ambient Air Quality Standards related to ozone risk assessments.

A second area of documented ecological risk is the deposition of acidic and acidifying deposition. ORD's work in this area will continue to focus on documenting changes in aquatic systems as a result of changes in deposition, analyses of data to document these trends, and work in the core program on improving the understanding of wet deposition processes. In addition, increased effort will be placed on understanding anthropogenic nitrogen influences from sources that include air.

Water

The Clean Water Act (CWA) provides the goals of restoring and maintaining the chemical, physical, and biological integrity of the nation's waters. To meet these goals, EPA initially focused on chemical measurements in the water column and on point source discharges. The major limitations of this approach were the lack of information on non-point source contributions, the inability to measure chemical movements through the food chain, and the lack of information on nonchemical impacts (e.g., habitat modification). To begin to address these limitations, EPA is beginning to supplement chemical measurements in the water column with other chemical measures, such as information on sediment and fish tissue contamination. In addition, there is now a recognition that nonchemical stressors and sources need to be identified to help assist water resource managers make sound decisions. Finally, there has been a recognition that to meet the goals of the CWA (i.e., to restore and maintain specific water bodies) requires a more global and holistic view of the entire watershed and of sources of contamination and stress—the foundation of the core research program.

To help address some of these emerging water issues, better ways to measure and model the impact of different global and local sources and stressors to aquatic ecosystems need to be developed. A key tool to develop better models and measures is the development of indicators and the ability to link them back to sources (i.e., to provide source "signatures"). Improvements in stressor indicators, source stress, landscape characterization, improved contaminant fate and transport understanding, and overall measurements and models of ecosystem conditions are needed to assist EPA in the following areas: better documentation to support designated uses for specific water bodies, and how to maintain them; improved abilities to identify problem sources for specific water bodies, and how to correct them; better tools for monitoring compliance agreements with point source and non-point source discharges or other sources on adverse impacts on aquatic ecosystems; and, finally, better information on the status and trends of ecosystem conditions to help evaluate the effectiveness of current management initiatives and to help set priorities for future actions.

Specifically, research will focus on

- providing indicators and criteria to identify, assess, and manage aquatic stressors, including contaminated sediments; and
- delivering decision support tools and alternative, less costly wet weather flow control technologies for use by local decision makers involved in community-based watershed management.

Pesticides and Toxics

The study of the deliberate release of toxic chemicals to control plant and animal pests has always been one of EPA's most important research programs. Thousands of pounds of pesticides are sprayed each year on crops and other components of our ecosystem to control the pests associated with agricultural production. The sophistication of the agricultural crop protection industry has produced an agricultural production system that is the envy of the world. The United States produces more goods in less space than any other country in the world, in part because of the extensive use of pesticides. Recognizing the significant risks posed by the deliberate release of "poisons", an elaborate registration and evaluation process is required before any pesticide can be used. This has lead to the reduction in the use of persistent and chronically toxic compounds like DDT, which has brought about definite ecological improvements, such as the return of the bald eagle. The fact that a pesticide such as DDT is no longer used (nor would be considered for use today) is because of ORD's risk assessment process, which recognizes the importance of the direct and long-lasting effects of this type of chemical. As the persistent chemicals have become less important, the newer and less persistent pesticides have become the dominant chemicals used in agriculture today. Many of these are not very persistent, do not accumulate in the environment, and generally are safer for the environment. They are, however, very acutely toxic and have both direct and indirect effects on organisms and ecosystems. The SAB considers the use of these newer pesticides a local- to regional-scale risk, whereas use of the older, more persistent pesticides are viewed as a national-to global-scale problem. One of the most important assessment issues regarding pesticides today is the indirect or secondary effects associated with their use.

Research under this area focuses on individual chemicals/toxics, classes of chemicals/toxics, and other issues that may pose serious risks to both human health or ecosystems; are expected to require a shorter term, concentrated effort; and are determined to be of special concern to EPA or the administration. In 1998 and beyond, research efforts will be broadened to incorporate effects, exposure, and assessment questions for determining the reliability, uncertainties, and impacts of broad classes of environmental agents and the evaluation of methods and models for determining the impacts resulting from cumulative exposures/effects of multiple chemicals within ecosystems and at various scales of ecological organization. Specifically, research will focus on test methods; indirect effects measures; and cumulative, systems-levels measurement methods.

Hazardous Waste

In 1995, the United States incinerated approximately 48 million metric tons of municipal, pathological, and hazardous wastes. Additionally, there currently are about 300 municipal incinerators, 2,400 medical incinerators, 160 hazardous waste incinerators, 130 industrial furnaces, and 40 cement kilns that are burning these waste materials in various geographic locations throughout the United States. Spills and leaks of petroleum products and oils also are a serious problem affecting nearly every community in the United States.

Research topics that ORD will focus on are

- providing improved methods for measuring, monitoring, and characterizing complex wastes in soils and ground water; and
- developing more cost effective and reliable technologies for cleanup of contaminated soils and groundwater.

Multimedia

There is an increasing need to evaluate more holistic issues of environmental protection. Problems have grown in both scale and complexity to the point where managing them may be more likely than solving them. Therefore, the multimedia research area, the largest of ORD's financial and human resource categories, focuses on issues that are multimedia, multistressor, or multireceptor in nature. As such, much of the research in this category is most directly related to the core program. However, some specific projects of particular interest to both ORD and EPA are described below in more specific terms than in the core program.

The highest priority areas for research in this area are

- global climate change,
- UV-B,
- endocrine disruptors,
- exotic species,
- anthropogenic nitrogen, and
- regional risk assessment.

Research Planning

The challenge for the ecological research planning process is to maintain core capability and competencies, apply them to the greatest environmental threats, meet the needs of the multiple clients, and continue to maintain a focus on future environmental issues that have yet to become immediate threats or client concerns (i.e., the Rubik's cube problem addressed earlier). In light of these many, often competing interests, ORD ideally will undertake those projects that meet all of the following criteria:

- the project is related to improving the ability to measure and model ecosystem sustainability;
- the project allows ORD to maintain a focused core competency and to focus on future needs;
- the project reduces uncertainty in a high-priority environmental problem area; and
- the project is consistent with a short- or long-term need of the client's office.

Research Coordination

There are several opportunities for coordination across laboratories and centers in the Ecological Research Program; these include common interests in geographic locations, specific hazards, and research programs. To the extent possible, these opportunities are used to encourage expected joint planning.

The Mid-Atlantic region has been chosen as the primary research location for ORD's ecologically related research and is viewed as the best opportunity to maximize coordination to meet the goal of the Ecological Research Program. The location decision was based on the extensive monitoring data available in the area, the selection of this area as a multiagency monitoring and assessment pilot, and the interest and participation of the region and states. This data-rich area will be exploited by developing a research plan for the Mid-Atlantic region that will be coordinated by a leader selected from among the laboratories and centers.

Data Management

Ecological data will be managed as an ORD corporate resource. Use of environmental information management systems to administer the data and metadata will provide the opportunity to share data and tools throughout the organization. Managing the network of environmental information management systems will be coordinated by the science data management board. Individuals representing each laboratory and center will interact with the chairman of the board.

SECTION 1

Introduction and Rationale

Although there remains a need for single stressor/single receptor/single scale research, and that research must continue, the long-term priority of the ecological research program will be on the most complex of relative risk evaluations (i.e., multiple stressors/multiple receptors/multiple scales).

1.1 Rationale for the Program

Ecosystems provide valuable renewable resources and services such as food, fiber, water storage and flood control, wood for construction, biodegradation and removal of contaminants from air and water, pest and disease control, and amelioration of climatic extremes. To the extent that these goods and services are threatened by environmental pollution, they must be replaced at great expense by civil works, man-made chemicals, and increased use of nonrenewable energy supplies. Ecosystems also supply less critical, but nonetheless valuable opportunities for recreation and scientific discovery, as well as a walk in the woods or along the shore under clear skies.

Considerable progress has been made in reducing the most egregious harm to the environment from air and water pollution (e.g., areas of devastation around industrial plants and burning rivers devoid of fish). Much remains to be learned, however, to understand and avoid potential disasters on a tragic scale, such as forest decline, widespread epidemics of toxic microorganisms in estuaries, reproductive failure of wildlife because of the global transport and redistribution of persistent organic pollutants or destruction of critical habitat, the reappearance of vector-borne epidemic disease, and global climate change, to mention but a few.

In virtually every major environmental act, Congress has required that the United States Environmental Protection Agency (EPA) not only ensure that the air is safe to breathe, the water safe to drink, and the food supply free of contamination, but also that it protect the environment. As a result, EPA's Office of Research and Development (ORD) has established research to improve ecosystem risk assessment as one of the six highest priority research areas for investment over the next 10 years (EPA, 1997).

1.1.1 A Changing Ecological Perspective

The more that is learned from EPA's pollution control efforts, the more it is realized that past approaches are necessary but not sufficient to protect ecological resources. Although pollutant-specific and site-specific programs have resulted in a substantially cleaner environment, societal expectations for ecological and natural resource systems have not been achieved. The water may, in fact, be cleaner, but the fishery has not improved because of the continuing loss of stream-side habitat or diversion of water flow. More wetlands may be preserved, but the duck populations may continue to decline because surrounding agricultural practices increase the number of duck predators. Toxic waste discharges into the Great Lakes have been reduced, but concerns still remain about fish contamination from toxic air pollutants transported from afar.

Comparable issues face other agencies. Under the Endangered Species Act, heroic and often socially disruptive efforts are made to save species that are approaching the brink of extinction while awaiting the development of a broader approach to prevent rather than merely respond to such catastrophic events.

Problems such as these have led to great interest in the concept of "ecosystem management"—dealing with ecological systems as they are organized by nature rather than in piecemeal fashion or along political or program boundaries. Although there is widespread support for such a concept, it is not clear how best to put it into practice.

One of the major issues involved in the application of ecosystem management is the issue of ecological boundaries. Many ecological systems function over large areas that do not coincide with political and programmatic boundaries. These large systems have internal linkages that can transmit or accumulate impacts in ways that are often not evident from local, site-specific observations. This occurs for systems that have extensive hydrologic interconnections, such as the South Florida (Everglades) Ecosystem, the Great Lakes, the Chesapeake Bay, the Columbia River, and the Ogalala Aquifer. Oyster populations in Chesapeake Bay may be influenced as much by land use practices miles away in the Susquehanna River watershed as by local actions. Other ecological systems include important species that require large areas to maintain their populations, such as spotted owls and grizzly bears, or species that move great distances as the seasons change, such as salmon, migratory birds, and sea lions. Adequate upstream spawning habitat for salmon is insufficient to maintain productive population levels if river impoundments block their passage to and from the ocean.

Even those ecological systems without tight internal linkages or wide-ranging species present boundary difficulties. It may be necessary, for example, for larger ecological systems to have a widely distributed pool of biological diversity that provides a genetic reservoir on which local ecosystems can draw to adapt to constantly changing environmental conditions and disturbances. Key elements of this pool of regional biodiversity are at risk from cumulative demographic and resource use pressures in large terrestrial ecoregions such as the Great Plains and the Appalachian Highlands. Maintaining the pools at a regional scale, for example, is currently a most uncertain exercise.

Another issue facing application of ecosystem management is the perception of the relationship between humans and nature. Until recently a plentiful supply of unallocated open space provided a buffer for increased resource use and changing public values. This helped foster a "protectionist" approach to natural ecological systems—these systems were something apart from human affairs and to be set aside and kept pristine. This view of nature is rapidly changing as it becomes clearer that nature does not operate in small, separate pieces and that human activities now pervade the entire earth. There are no pristine ecosystems left—as a minimum, all natural systems are exposed to the changing composition of the atmosphere and solar radiation, and only a few are spared from the profound land use changes sweeping across the globe.

1.1.2 A Changing Regulatory Perspective

It is increasing clear that solutions to ecological issues no longer can be isolated to one stress, one scale, or one media. It is also obvious that increasingly environmental problems cannot be solved but rather must be managed, interactively. Society, scientists, and regulators also now recognize that not all ecological changes are "bad". In many instances, ecological change has to be evaluated in terms of what is wanted from ecosystems. Ecosystem management becomes more a matter of social trade-offs among alternative uses rather than simply a matter of protection. People are part of ecosystems—cultural, economic, and ecological well-being have become inextricably linked.

The regulatory approach within EPA also is evolving to meet the ecological protection challenges being faced. In particular, there are two changes that will have a major impact on the future of environmental protection.

(1) **Less centralized decision making**—In the past, there has been a “command and control” approach to regulation. Although that certainly will continue in many areas where it is the only way to achieve results, when it comes to protecting ecosystems, it is clear that the values of the community must factor into the process. As such, there will be increasing movement to community-based decision making.

(2) **More flexible decision making**—As with centralized decision making, the regulations have been made clear, unbending, and applicable nationally. Recognizing that "one size does not necessarily fit all" and that alternatives, in fact, do exist, increasingly the results are the focus rather than the means to that end.

The combination of these two changes have significant implications for the research community. Maybe most scientifically important, there must be a better understanding of ecosystem sustainability so that within the boundaries chosen, the endpoints of interest to society, and the alternative management strategies chosen, EPA can ensure the protection of the nation's ecological resources and that the desired environmental goals continue to be met.

These changes in both the scientific understanding and the regulatory approach to protecting ecosystems, provide the foundation of ORD's Ecological Research Strategy. Specifically, the goal of this research is to determine how to sustain ecosystems and determine the relative risk posed to ecosystems as a result of exposure to multiple stressors and, possibly most importantly, at multiple scales.

1.1.3 Assumptions About Ecosystem Management

Although there is increasing agreement in principle with the concept of ecosystem management, there is no generally recognized model for its application. In attempting to provide the scientific basis for EPA's application of ecosystem management, this strategy makes several key assumptions (presented below), all of which tend to represent the ideal rather than the current capabilities to achieve their intent.

Ecosystem management is "place-based" management. Ecosystems tend to be spatially defined. Therefore, this strategy will focus on geographical units that have ecologically determined boundaries.

- **Ecosystem management must be holistic rather than piecemeal.** Ecosystems have multiple components and functions that are affected by multiple, interacting stressors. Therefore, ecosystem management must integrate all relevant ecological endpoints and stressors.
- **Ecosystem management must occur at multiple scales.** Ecosystems function at multiple, interacting scales, and different management decisions are applicable at each scale. This strategy will deal explicitly with several ecological scales.
- **Ecosystem management is driven by public values.** People and nature are not separate; ecological systems provide multiple, often competing, values to society. Therefore, there is no single, scientifically derived endpoint for ecosystem management. Ecosystem management involves a balancing of competing interests.

Therefore, ecological research also must change if it is to continue providing the sound scientific foundation for meeting the needs of the changing regulatory process.

It is the intent of ORD's Ecological Research Program to further understanding of ecosystems to improve the ability to conduct ecological risk assessments. To accomplish this objective, research is needed in the areas of monitoring, process and modeling, assessment methods, risk management, and ecosystem restoration. These research areas will serve as the broad areas of interest over the next 3 to 5 years for this research strategy.

Progress in this program will insure within ORD that the highest priority research can be identified. From EPA's perspective, the goal is to provide solutions to environmental problems founded on sound science.

1.2 ORD's Ecological Research Program

ORD has developed and published a strategic plan as a guide to how research will be conducted within the organization. It presents, the vision and mission of ORD, the strategic principles that are to be followed, and the foundation for selecting ecological research as one of the high-priority areas of research. The strategic plan also discusses the priority-setting process and how decisions are made relative to who should conduct the needed research within the priorities chosen. Therefore, these issues will not be revisited in this document, and the reader is encouraged to review the strategic plan because it provides, to a great degree, the "first order" boundaries on the Ecological Research Strategy.

There are two issues, however, that require discussion and consideration in this document that provide additional perspective and boundaries for the program:
(1) the ecological risk assessment process, and
(2) the Government Performance and Results Act (GPRA).

Although the first item is discussed in the ORD strategy, it is worth additional discussion here. As for the second item, it is having a significant influence on the work to be done by ORD and is evolving. As such, it is important background information for understanding the presentation of the ecological research to follow.

1.2.1 Ecological Risk Assessment

The risk assessment paradigm has been chosen as the organizational structure for and the guiding approach to all research within ORD. This paradigm is described in Figure 1-1. It serves as an excellent organizing structure for the research program. It also provides two key focal points of interest to the research efforts: (1) the ability to characterize risk (also, within the context of this document, discussed in terms of vulnerability and sustainability) and (2) the ability to provide appropriate risk management strategies.

Most of the terminology and concepts have been derived primarily from many years of research in the field of human health risk, with the endpoint often being cancer risk. Following the paradigm for any individual stress, individual organism, and single endpoint is difficult. The application of the risk model for ecological risks presents some significant differences and increased complexities. Among them are

- multiple, interactive, and interdependent species of concern;
- multiple scales of concern, over which these species exist and interact;
- multiple endpoints that are of importance to society; and
- more of a willingness to sacrifice ecosystems to better meet multiple societal interests.

Stated most simplistically, the challenge in the ecological research area is to develop risk assessment and management strategies for

- individual stressors (chemical and nonchemical, natural and anthropogenic) and individual receptors (ecosystems, ecosystem components, communities, populations, and valued societal goods and services—endpoints);
- individual stressors and multiple receptors;
- multiple stressors and individual receptors; and
- multiple stressors and multiple receptors.

The uncertainty in risk characterization increases as the more complicated combinations are considered, particularly when the interactions among stressors and receptors are considered. Added to the complexity is the need to also conduct risk characterization at multiple scales and the fact that nonchemical stressors may be more important than chemical stressors (for which most of the concepts in risk assessment have evolved) in ecosystems.

Therefore, although there remains a need for the more "traditional" single stressor/single receptor/single scale research, the dominant long-term focus of the ecological research program will be on the most complex of relative risk evaluations (i.e., multiple stressors/multiple receptors/multiple scales). If EPA's goal of providing more flexible and decentralized decision making is also to be met, it is increasingly important to continue to improve the ability to quantify ecological risks for that purpose.

It also should be noted that the current ability to use the paradigm for selection of the highest priority research, as proposed in the ORD strategic plan, is at best marginal. Although there is general agreement on the criteria, there is no agreement on the relative risk posed by multiple stressors, at multiple scales, on multiple endpoints, except in the most extreme situations. Thus, the priorities for research and regulatory action in the absence of scientific certainty introduce considerable subjectivity and variability to the selection process. One of the benefits of this research program will be to make the

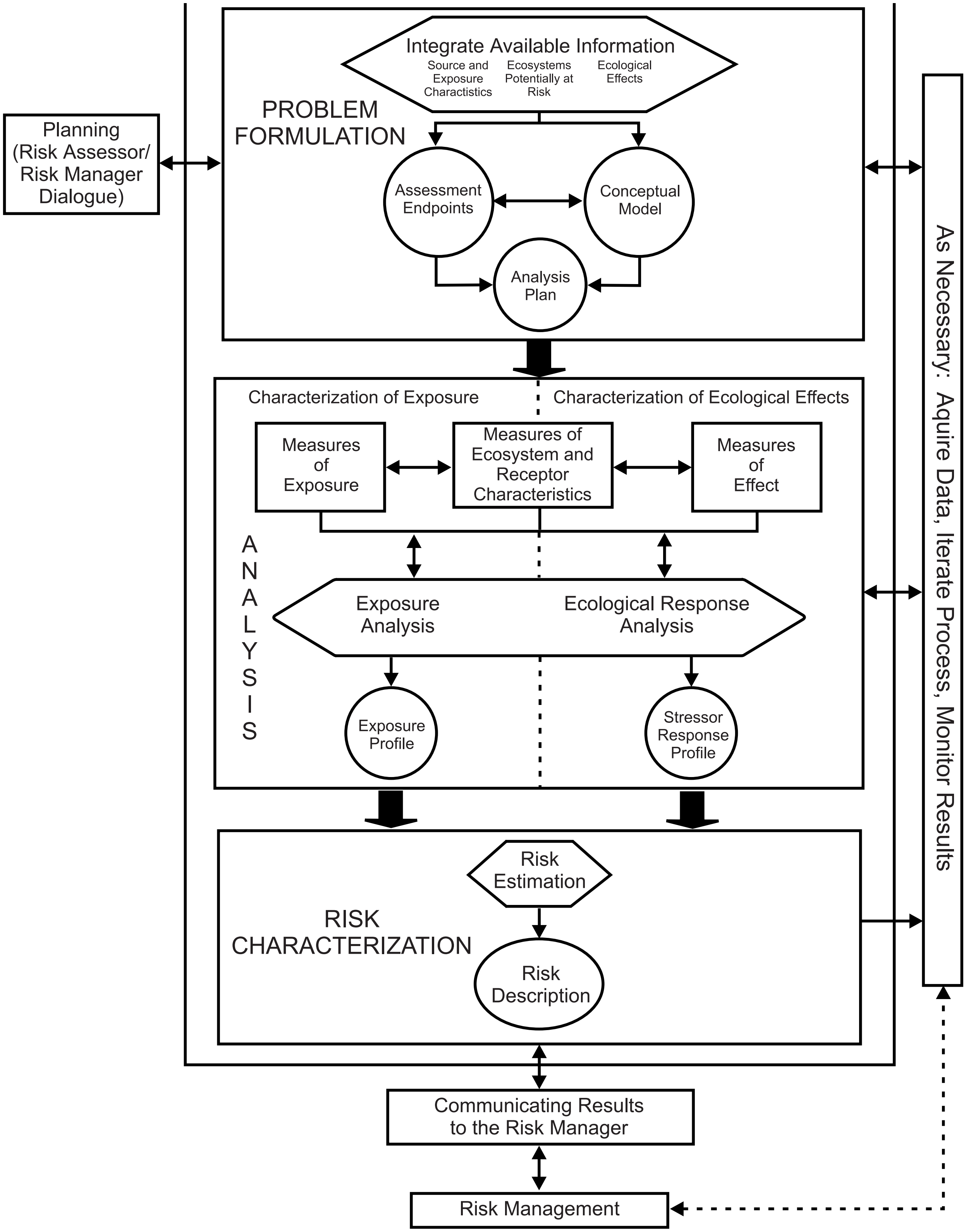

Figure 1-1. The ecological risk assessment framework (U.S. EPA, 1992a), shown as a three-phase process, with an expanded view of each phase. Within each phase, rectangular boxes designate inputs, hexagonal boxes indicate actions, and circles represent outputs.

process of priority setting (i.e., determining what research to fund or what regulatory action to take) far more defensible over the next 5 to 10 years.

1.2.2 Government Performance and Results Act

The current administration has required all federal agencies to better account for their proposed results. EPA has, therefore, been developing a cascading set of goals, objectives, subobjectives, and milestones in compliance with GPRA. There are 10 EPA goals:

(1) clean air;
(2) clean, safe water;
(3) safe food;
(4) safe communities, homes, workplaces, and ecosystems;
(5) safe waste management;
(6) global and transboundary environmental risk reductions;
(7) empower people with information and education and expanding their right to know;
(8) provide sound science to improve the understanding of environmental risk and develop and implement innovative approaches for current and future environmental problems;
(9) provide a credible deterrent and promote compliance; and
(10) effective management.

ORD has a role to play in most, if not all of these goals. One in particular is of importance—sound science. It is this goal that provides the foundation or core science for ORD's Ecological Research Program. The specific objective associated with the proposed ecological research is entitled, "Research for Ecosystem Assessment and Restoration" (i.e., to provide the scientific understanding to measure, model, maintain, or restore, at multiple scales, the integrity and sustainability of ecosystems now, and in the future).

Two other sound science objectives are also of particular importance:

(1) emerging risk issues—establish capability and mechanisms within EPA to anticipate and identify environmental or other changes that may portend future risk, integrate futures planning into ongoing programs, and promote coordinated preparation for and response to change; and
(2) pollution prevention and new technologies for environmental protection—develop and verify improved tools, methodologies, and technologies for modeling, measuring, characterizing, preventing, controlling, and cleaning up contaminants associated with high-priority human health and environmental problems.

Collectively, these goals assist in driving the core research program that will be presented in Section 3. The goals and objectives of the client offices will be presented as applicable in Section 4. These later objectives and subobjectives determine how the core capabilities in the program are applied to immediate EPA problems.

1.3 Purpose and Structure of This Document

The purpose of this document is to present the goals, objectives, and priorities for the Ecological Research Program. The document presents an overview of the critical questions and activities that constitute the focus of the Ecological Research Program over the next 3 to 5 years.

Section 2 introduces the basic themes of the strategy. Section 3 provides an overview of the priorities and direction of the core research program that is conducted within the above-stated GPRA objectives. Section 4 presents the high-priority EPA research selected for application of the core capabilities, and Section 5 provides insights as to how the research program will be planned and conducted.

The intended audience for this document is the scientific community and in-house scientists.

1.4 References

U.S. EPA (1992) Framework for Ecological Risk Assessment. EPA/630/R-92/002, Risk Assessment Forum, Washington DC.

U.S. EPA (1997) Update to ORD's Strategic Plan. EPA/600/R-97/015. 74 pgs.

SECTION 2

Ecological Research Program Strategic Direction

The goal of the Ecological Research, Assessment, and Risk Management Program is to "provide the scientific understanding required to measure, model, maintain and/or restore, at multiple scales, the integrity and sustainability of ecosystems now, and in the future."

2.1 Introduction

The foundation necessary for local communities to avoid costly environmental management failures by better understanding stressor exposures to, effects on, and restoration of the nation's ecological resources, can be improved by ecological research in ORD. Therefore, research to improve ecosystem risk assessment and risk management has been selected as one of the seven highest priorities on the ORD research agenda.

The goal of the Ecological Research Program is, therefore, to "provide the scientific understanding required to measure, model, maintain and/or restore, at multiple scales, the integrity and sustainability of ecosystems now, and in the future."

In the context of this program, ecological integrity is defined in relative terms as "maintenance of ecosystem structure and function characteristic of a reference condition deemed appropriate for its use by society." And, relative sustainability is defined as "the ability of an ecosystem to maintain relative ecological integrity into the future." The goal of this program, as stated in Section 1, is also the objective of EPA's GPRA sound science goal.

It is ORD's vision that by 2008 EPA researchers will have developed the next generation of measurements and models necessary to secure the present and probable future sustainability of ecosystems at local, watershed, and regional scales. Obviously, this is not a vision or goal that can be accomplished by ORD alone and will be dependent on contributions from in-house and extramural programs, other agencies, the academic community, states, and others. Research within ORD then must be prioritized, capitalizing on the strengths of the organization and the needs of clients most closely supported by it.

2.2 Scientific Questions

The scientific questions, consistent with the program goal, that will be the primary foci of the research are

- what is the current condition of the environment, and what stressors most significantly affect the condition? (monitoring research)
- what are the biological, chemical, and physical processes affecting the exposure and response of ecosystems to stressors? (process and modeling research)
- what is the relative risk posed to ecosystems by these stressors, alone and in combination, now and in the future? (risk assessment research) and
- what options are available to manage the risk to or restore degraded ecosystems? (risk management and restoration research)

The primary focus of all activities is the relative risk posed by the stressors, because it represents an endpoint of the research that not only will assist EPA in making the most cost- and environmentally effective management decisions, but also will be critical in guiding the ecological research needs of this program. If successful, the scientific understanding required to ensure that environmental decisions are focused on the problem of most significance and where limited resources can be used most wisely will be improved significantly over the next 10 years.

2.3 Program Objectives and Core Research

Consistent with the scientific questions that must be addressed and the subobjectives of EPA's GPRA sound science goal, the program is developed around four fundamental research objectives (GPRA subobjectives):

(1) monitoring research—developing indicators, monitoring systems and designs for measuring the exposures of ecosystems to multiple stressors and the resultant response of ecosystems at local, regional, and national scales;

(2) processes and modeling research—developing the models to understand, predict, and assess the current and probable future exposure and response of ecosystems to multiple stressors at multiple scales;

(3) risk assessment research—developing and applying assessment methods, indices, and guidelines for quantifying risk to the sustainability and vulnerability of ecosystems from multiple stressors at multiple scales; and

(4) risk management and restoration research—developing prevention, management, adaptation, and remediation technologies to manage, restore, or rehabilitate ecosystems to achieve local, regional, and national goals.

The goal of this program is consistent with the objective of EPA's GPRA for "Sustainable Ecosystems and Restoration" and the objectives of the program are the same as the GPRA subobjectives (see Section 1).

These four objective areas are also consistent with the historical strengths of ORD's research (i.e., the core research of ORD). Similar to disciplinary departments in academia (e.g., botany, chemistry, zoology, math, statistics, physics, to mention but a few), these four areas represent ORD's primary capabilities in ecological research, assessment, and risk management. As such, they have been chosen as the organizing framework for the research strategy.

ORD has numerous clients that must be considered in the development of the research program. The research then can be organized by the needs of any of these client interests. However, this leaves the fundamental research program difficult to present and extremely volatile because these needs change. Using the university structure as an example, the departments do not change over time, but rather the research within the departments change significantly for many reasons, such as new advancements in science or new opportunities for funding. Similarly, the ecological research strategy is then first and foremost aimed at defining the fundamental core research program (Section 3). The application of these capabilities to specific, high-priority issues is presented in Section 4. This approach might best be viewed as a Rubik's cube, and the elements are the research projects that can be arrayed many different ways.

2.4 Strategic Principles

To meet the goal of the program, there must be a close working relationship between EPA's laboratories and centers. To ensure this relationship, in addition to the common objectives and core research are several strategic elements that will be common to the research.

First, consistent with the reorganization of ORD, the risk paradigm, the goal of the program, and the core research areas, two common endpoints have been chosen to guide research planning: (1) assessing ecosystem sustainability and (2) maintaining and restoring important ecosystems. Although there is considerable controversy about sustainability, its applicability as an endpoint, and even its definition, the need to resolve this controversy, focus on it, and incorporate this broader goal into the risk assessment guidelines of the future are not lessened.

In addition, three general issues need to be at the forefront of improving the ability to make ecosystem management decisions in the future (considering more flexible regulations and decentralized decision making) and to guide ORD research. These areas for research include more emphasis on the relative risk and, therefore, a better understanding of the impact of multiple stressors, at multiple scales, and at multiple levels of biological organization (see Section 1). Although these are not new areas for research in ORD, the core program will emphasize explicitly research considering these interrelated issues over the next 5 to 10 years.

- **Multistressor research.** To manage risks, it is important that the endpoint and the stressor affecting it are known. Also, to improve management success, it is equally important to understand all the other stressors that interact with the receptor. Thus, the challenge will be to compare the relative risk of multiple stressors acting alone and in combination on all levels of biological organization and geographic scales. Only through this information can action be taken that will ensure the desired result. Actions too often are taken that have unintended consequences and fail to achieve the desired result because of a lack of understanding. Therefore, the long-term research program will focus on ways of partitioning the influence of multiple stressors on individual and multiple receptors, particularly at watershed and larger scales.
- **Multiple levels of biological organization.** More research has focused on individual organisms and species than on any other level of biological organization. New technologies more easily allow research at the molecular level. However, the higher levels of biological organization (e.g., populations, communities, systems) must be investigated as well. Therefore, the research will focus on developing an improved understanding of effects and exposure mechanisms at all levels of biological organization but with a high priority given to the molecular, community, and landscape levels.
- **Multiscale research.** It is clear that there is an improved awareness of the need to look more holistically at the environment. All too frequently, by not doing so, unintended consequences of ignoring the complex linkages among ecosystem elements have occurred. EPA now has taken a bold step forward to provide local decision makers with a more flexible decision process at watershed and other biologically and ecologically relevant scales. However, it is important to recognize that, although this is certainly a significant step forward, the collective decisions at the local scale can affect increasingly larger scales. Therefore, one of the important challenges facing ORD is better understanding the relationships of environmental processes among multiple scales to provide guidance at local, regional, and national levels of environmental management. In particular, the regional scale will be of priority as it is a scale that uniquely can be addressed by the federal government.

The combination of the endpoints, the relative risk of multiple stressors action alone and in combination, the watershed and larger geographic scales, and the community and landscape levels of biological organization provide a strategic focus for the long-term research within the program that should continue developing the foundation of science needed for future decision making. It also will be balanced, as shown in Section 4, with the immediate needs of EPA, which actually offer opportunities consistent with the strategic direction of the program.

2.5 Organizational Structure

In ORD, there are three laboratories and two centers. The focus of the research program is on the three laboratories (the National Health and Environmental Effects Research Laboratory [NHEERL], the National Exposure Research Laboratory [NERL], and the National Risk Management Research Laboratory [NRMRL]) and one center (the National Center for Environmental Assessment [NCEA]). The National Center for Environmental Research and Quality and Assurance is (NCERQA) also part of the strategy as it provides the guidelines for EPA's Quality Assurance Program, which ORD follows, and the extramural grants program, a mechanism by which much of the needed research within the program will be accomplished. Additional information about the organization of ORD and other components are presented in the ORD strategy.

Each laboratory and center has a unique role to play in these core research areas within the risk model. In addition, however, there are also secondary and supporting roles to be played by each (Table 2-1).

Table 2-1. Summary of general emphasis of core area research within the Ecological Research Program at the participating laboratories and centers.

Core Research Areas	National Health and Environmental Effects Research Laboratory	National Exposure Research Laboratory	National Center for Environmental Assessment	National Risk Management Research Laboratory
Monitoring and Monitoring Research	Primary	Primary	Supporting	Supporting
Processes and Modeling Research	Primary	Primary	Supporting	Supporting
Assessment Research	Secondary	Secondary	Primary	Secondary
Risk Management and Restoration Research	Supporting	Supporting	Supporting	Primary

Coordination across laboratories and centers, as well as participation by other agencies, institutions, and organizations, is essential to achieving the goal of the program. Figure 2-1 shows the conceptual approach, mapped to the core research agenda, for research to be conducted within the base program. Of particular import is the necessity for sharing information and planning research across organizations. These coordination and management issues will be discussed in Section 5.

2.6 Fundamental Science Priorities To Support the Ecological Research Strategy

The next section of the strategy discusses the core research program in monitoring, modeling, assessment and risk management, and restoration research. It is not the intent of this strategy to ignore or minimize short- or long-term client needs (these will be addressed specifically in Section 4); however, as noted earlier, the long-term responsiveness of ORD depends on its capability to maintain a focused core program that can be applied to the current and future needs of EPA. This core program represents a significant portion of ORD research; provides the bases for hiring future scientists; and, in reality, much of the work is fully consistent with meeting the immediate needs of the client offices, as well as the core program. How the program will be planned and its relationship to the client priorities are discussed in Section 5. Using the common framework and the scientific questions as a guide, there are a number of essential areas of basic research that need to be developed and will serve as the primary research foci over the next 3 to 5 years.

Of particularly high priority (all of which will be put into the context of the core program in the following section) will be

- monitoring research—focused on indicator and criteria development at molecular, community, and landscape levels of biological organization, new characterization methods and technologies, and monitoring designs;
- model development—focused on improving first principle exposure and effects models, coupling and scaling of effects and exposure models, and developing a common modeling framework;
- risk assessment—focused on developing guidelines and place-based assessment methods and conducting special assessments;

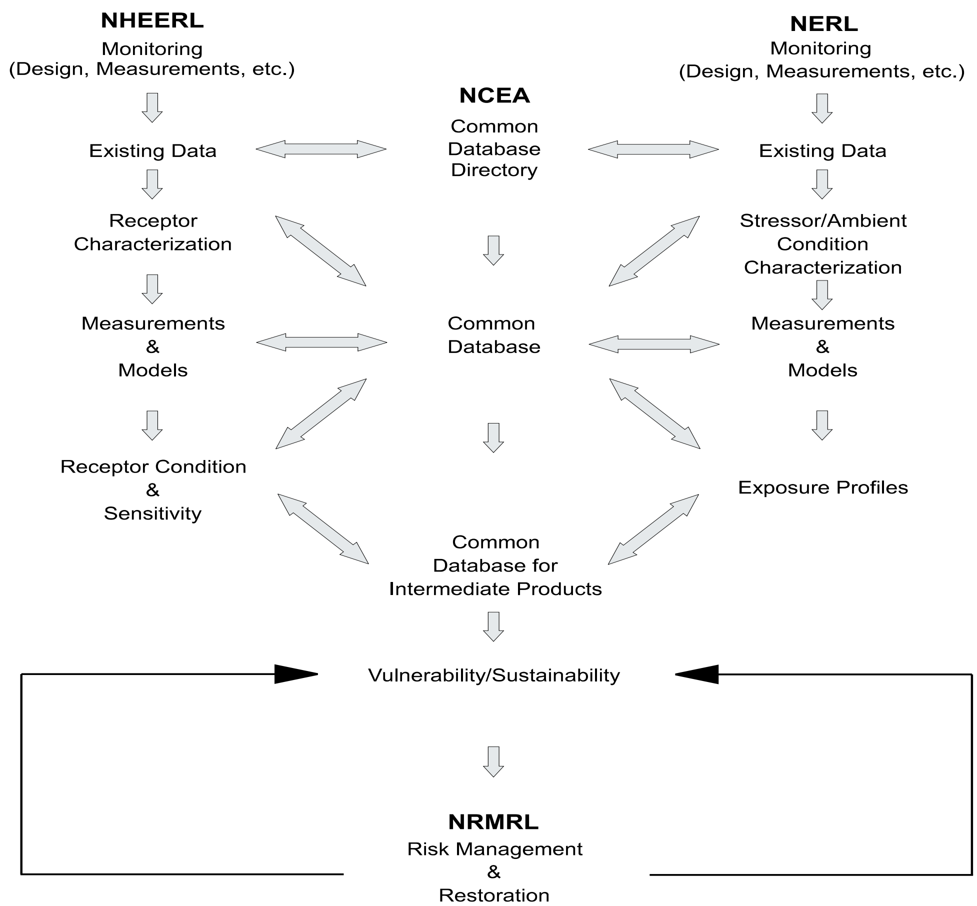

Figure 2-1. ORD Ecological Research Strategy.

- risk management and restoration research—focusing on watershed and larger scale pollution prevention, management, adaptation, remediation, rehabilitation, and restoration technologies for aquatic systems.

A summary of the program direction, example tasks, and selected products is shown in Table E-1. More detailed goals, milestones, and strategic selections are, again, in the following section.

SECTION 3

Core Research Objectives, Rationale, and Focus

A core research program is fundamental to being able to meet both the current and future needs of EPA. Therefore, ORD will maintain a fundamental and applied research program in the following areas:

- ***ecological monitoring research,***
- ***ecological processes and modeling research,***
- ***ecological risk assessment research, and***
- ***ecosystem risk management and restoration research.***

3.1 Introduction

Underlying the ability for ORD to be responsive to the current and future environmental protection needs of EPA is a long-term, fundamental and applied research program in four areas:
(1) monitoring research,
(2) process and modeling research,
(3) risk assessment research, and
(4) risk management and restoration research.

This "core" research program is consistent with ORD's vision—"...provide the scientific foundation to support EPA's mission"—and specifically designed to meet two of ORD's mission elements: (1) "perform research and development to identify, understand, and solve current and future environmental problems and" (2) "provide leadership in addressing emerging environmental issues and in advancing the science and technology of risk assessment and risk management." Guiding the core research, as with the problem-focused research in Section 4, are defined goals and objectives to meet the GPRA requirements (see Section 1). The four topics above are directly aligned with the four primary subobjectives of the ecological objective of the sound science goal (Sections 1 and 2).

As discussed in Section 2, these four areas have historically been strengths in ORD and will continue to serve as the foundation for research into the future. How this expertise is applied to EPA needs will change as environmental issues change, but a basic research program will be maintained in each of these major areas. Section 4 specifically discusses how these core capabilities will be used to address high-priority issues over the next few years. Because of the close relationship in the core research and programmatic needs, there will be some redundancy in the materials presented in Sections 3 and 4. The difference, however, is the specificity of the research in the two areas. Section 5 will present the conceptual overview of the planning to show how the core and its applications are linked.

The sections that follow provide an overview of the direction of the core research program that will be undertaken over the next 3 to 5 years. As a strategy, the intent is to present what work is to be done and why, but not how—except to the extent that it will be done either within ORD or through the grants program. The research represents a composite of capability. However, the intent will be to focus on continually improving the ability to quantify relative risk to ecosystems and to manage those risks. Section 2 presented the conceptual organization for the research, and Section 4.6.3.7 is one example of how the collective work of the laboratories and centers will be brought together to meet a common goal within GPRA. GPRA subobjectives and milestones will be provided where appropriate to further assist in understanding why the research has been undertaken.

Additional research strategies and plans to complement both the core and problem-focused research (Section 4) are or will be made available. They provide more detailed information about how the research will be conducted. Table 3-1 lists those research strategies and plans that are applicable to the Ecological Research Strategy and are now being prepared or completed. This information will be useful to the reader seeking a more detailed understanding of the research to be conducted.

3.2 Ecosystem Monitoring Research

Government Performance and Results Act Subobjective:
Develop indicators, monitoring systems, and designs to measuring the exposures of ecosystems to multiple stressors and the resultant response of ecosystems at local, regional, and national scales

With rare exceptions, ecosystem monitoring has been conducted to meet short-term or program-specific objectives, and it seldom is harmonized or coordinated across large geographic areas. Comparable measurements are taken for only a short time (e.g., less than the length of many natural ecological cycles) across a large area, or, when measurements are made over a long period, they usually are restricted to one or a few study sites. Recently, however, there has been revived interest in creating a multiagency ecological monitoring network that would monitor the condition of ecosystems and provide periodic “report cards” to the public.

Early experience with EPA’s EMAP revealed that there remains a great deal of scientific controversy over what to measure and with what network design. The emerging consensus, based in large part on the ecological risk assessment paradigm, is that indicators of exposure (i.e., the juxtaposition of a stressor and an ecological receptor in time and space at a comparable and appropriate scale) and effect (i.e., the actual change in an ecological receptor, again at a number of relevant and appropriate scales in time and space) should be simultaneously monitored. Additionally, environmental characteristics that modify the exposure/effect relationship (i.e., characterization), as well as exposure indicators that signify the occurrence of a past exposure, perhaps in episodes or cumulatively over long periods of time, also need to be monitored.

With respect to monitoring design, there is also an emerging consensus that a hierarchical, tiered design is necessary. Such a design employs statistical surveys or coarse-scale coverage, using remote sensing to conduct periodic surveillance on large areas, along with more intensive monitoring (both in time and space), occurring at representative sites of interest. Indicators must be adapted to the appropriate tier of monitoring and, yet, linked across the tiers.

The monitoring research strategy sets a course to improve monitoring technology in indicators, environmental characterization, new technologies, and network design. It retains a degree of disciplinary focus (e.g., remote sensing, environmental analytical chemistry, toxicology, landscape ecology, community ecology) necessary for progress, but it is the goal to insure that the interconnections among the indicator, design, and technology elements lead ultimately to an integrated solution to a successful national ecological monitoring program.

3.2.1 Indicator Development Research

Government Performance and Results Act Subobjective:
Develop suites of new, field-applicable biological indicators and criteria for measuring, understanding, and diagnosing ecosystem exposures, effects, and recovery

Table 3-1. Companion ORD research plans or strategies to the Ecological Research Strategy.

Companion Plan Titles	Short Synopsis of the Plan Focus
Endocrine Disruptors	At present, the hypothesis that endocrine disrupting chemicals are causing adverse health in the wildlife and humans remains intriguing. Most of the knowledge and concerns to date have arisen from situations with relatively high-level exposure to persistent organic pollutants or therapeutic use of pharmacological agents. For proper regulatory action to occur, the understanding of the potential scope of endocrine disruption in humans and wildlife must be expanded, including definition of the range of health effects, critical life stages, sensitive species, and exposures relevant to alterations in endocrine function; and development of risk management options to reduce or prevent additional adverse effects in populations.
Environmental Monitoring and Assessment Program (EMAP)	This program develops the science of measuring ecosystem health and for monitoring the condition and trends of natural resources at the regional scale. Using the White House Committee on the Environment and Natural Resources (CENR) National Monitoring Framework and interagency workgroups as guides, EMAP supports complementary intramural and extramural Science to Achieve Results (STAR) research programs to develop more cost-effective ecological indicators and to design multiple-tier monitoring methods capable of detecting trends and associating ecological impacts with likely stressors. The indicators and monitoring designs intended to support state-, regional-, and national-level environmental report cards encompass multiple stressors and many resource classes such as estuaries, streams, lakes, wetlands, forests, and grasslands.
Global Change	Based on the findings of the Intergovernmental Panel on Climate Change (IPCC); guidance in ORD's strategic plan; and the priorities specified in FY97, *Our Changing Planet* by the U.S. Global Change Research Program (USGCRP), ORD will strategically invest in global change research. ORD's Global Change Research Program will focus on ecological vulnerabilities of ecosystems to climate change, the implications for human health, and mitigation and adaptation approaches. The research conducted will provide policy makers with information on potential ecological and human health consequences of climate change and technical data needed to evaluate alternative greenhouse gas emission reduction and adaptation approaches.
Pollution Prevention	For pollution prevention to be a success, all stakeholders (e.g., regulators, industry, environmental groups) must have access to scientifically sound pollution prevention technologies and approaches. They also must be able to measure and objectively evaluate the viability and comparative environmental performance of these pollution prevention technologies and approaches. There is a lack of user-friendly tools and methods to compare pollution prevention solutions with each other and to end-of-the-pipe solutions, and there is also a lack of proven pollution prevention technologies and approaches for many pollutant sources in a number of economic sectors. Research is being undertaken in pollution prevention to address fundamental knowledge gaps in both of the above areas—(1) tools and methods and (2) technologies and approaches.
Waste	The goal of the ORD Waste Research Strategy is to set forth an effective research program to understand and reduce human and ecological exposure to toxic materials released during waste management, and to assess and remediate contamination that has occurred because of improper waste management. Focus is directed toward research on groundwater and on soils and the vadose zone at contaminated sites, on active waste management facilities, and on emissions from waste combustion facilities. Associated technical support activities to assist EPA program offices and regions and other stakeholders also are described.
Indicator Development	Measuring the integrity and sustainability of ecosystems requires the development and understanding of "indicators" of critical ecosystem characteristics. ORD's strategy for ecosystem protection and the subcomponent, EMAP, place a high priority on the development and implementation of effective measures of important ecosystem attributes. This research plan builds on past research in EMAP and will outline the major gaps in the ability to measure and interpret the integrity and sustainability of ecological resources at multiple spatial scales and to diagnose the causes of impairment. Based on these analyses, ORD will propose the portions of these gaps that will be addressed through research by the EPA ORD staff and prioritize the indicators that should receive research attention through the STAR grants program.
Ecosystem Restoration	An ecosystem restoration strategy and research plan has been prepared and peer reviewed by NRMRL. The strategy develops the rationale for restoring watersheds using an array of rehabilitation and stressor reduction technologies and for providing decision support systems for watershed restoration groups. The program will be implemented via an in-house competitive proposal approach and participants are seeking partnerships with other ORD investigators in NERL, NCEA, and NHEERL. The Office of Water is included in the proposal evaluation stages to ensure relevancy. On-going and future restoration projects in the regions will be used as appropriate test beds for the developed technologies.
Contaminated Sediments	A contaminated sediment planning group has been convened within ORD to develop a research strategy. In some cases (e.g., sediment quality), criteria development has been an ongoing area of research that will continue. In other cases (e.g., remediation of contaminated sediments), new work has been initiated. In this case, and as a follow-up to the recent NRC recommendation on the subject, NRMRL has engaged the Corps of Engineers in a discussion of joint projects and programs.

3.2.1.1 Background

Monitoring serves multiple functions. It is certainly a tool to assist in determining if there is an environmental problem, and, if so, how big the problem is and where it is of most concern. Monitoring is also essential in helping to determine what is causing problems that are of concern and the relative importance of multiple stressors; it plays a role at all levels of the risk assessment process. Clearly, these functions of monitoring require utilization of retrospective monitoring (i.e., has an effect already occurred?) and prospective monitoring (i.e., given current or projected levels of stressors, is an effect likely to occur?). Both of these functions of monitoring assist in targeting resources—resources directed at solving environmental problems and resources expended on research related to environmental concerns. Once decisions about management actions are made, monitoring becomes critical to determining if the decisions and actions resulted in the changes or improvements expected. Central to all of these functions are the decisions about what should be monitored to meet the objectives.

It is clearly impossible to measure all environmental changes, and the concept of indicators is simply an expression of efforts to summarize which elements of environmental change should be tracked and will provide the greatest information return for the least investment. The distribution and intensity of stressors generated by human activities and threatening ecological resources are uncertain. It is not known which stressors place ecosystems at most serious risk. Also unknown is the condition of the resources or the extent to which critical ecological processes are being impaired. There is fragmented knowledge of places with obvious, detrimental impacts but less knowledge about the more pervasive and extensive ecological problems. Furthermore, limited means exist to sample and to make the measurements that will provide the kind of scientific data needed to understand, predict, and resolve potential environmental threats.

ORD research on indicators must contribute to developing an understanding of the conceptual basis for defining sustainability and integrity for single ecological resources and complexes of ecological resources. What are mechanistic models for these concepts from which can be developed a foundation for monitoring? What are the ecological units of organization for which sustainability and integrity can be described? Are watersheds, ecoregions, or landscapes the ecological units that are best suited for describing sustainability and integrity? Can individual ecological resources such as lakes, streams, forests, or rangelands exhibit sustainability and integrity, or are these concepts applicable only to complexes of ecological resource types?

Sustainability and integrity do not necessarily imply a steady state or a desire to maintain the status quo. Ecosystems are dynamic both in space and time. Recognition of this dynamic character makes the selection of a benchmark or yardstick against which to evaluate current conditions a research challenge. Indeed, this has been the challenge throughout the development of chemical and biological criteria within EPA's Office of Water. When human health is the concern, dose-response studies of individual chemicals form a basis for the development of chemical criteria. The effort to develop similar criteria relevant to evaluating sustainability will be significantly more difficult. Prototypes do exist, and their strengths and weaknesses require careful evaluation.

An "Indicator Development Research Plan" for ORD that will organize and prioritize the in-house EPA research efforts on indicators is being developed. The ORD indicator plan will be available in the fall of 1997. This plan also will contain a refinement of the indicator development evaluation criteria described by Barbar (1994). Therefore, what follows is only a brief summary of the process and areas for research.

3.2.1.2 Indicator Development Framework

Fundamentally, an indictor is

> "any expression of the environmental that quantitatively estimates the condition of ecological resources, the magnitude of stress, the exposure of biological components to stress, or the amount of change in condition."

The indicator may be a single-field or remotely sensed measurement, or it may be an index based on multiple-field or remotely sensed measurements. The output of a mathematical model also may be used as an indicator. ORD's four-point goal is to identify and select indicators that (1) quantify biological condition relative to integrity and sustainability and quantify the stressors to which the biota are exposed, (2) meet the indicator selection criteria, (3) can be incorporated into one of the three monitoring tiers (index sites, regional surveys, or remote sensing), and (4) can be used in ecological risk assessment.

The research plan and the criteria guidelines under development will outline in detail the evaluations to which indicators will be subjected. However, these are five basic questions that must be answered.

(1) **What should be measured?** Requires a conceptual model of the system, an evaluation of the potential use of various levels of biological organization, and the classes of stressors that are potentially important for that resource and scale. Table 3-2 summarizes the biological levels of organization that will be considered.
(2) **How should the indicator be measured?** Requires that a standard protocol be defined.
(3) **How responsive is the indicator?** Evaluating the degree to which a particular indicator actually responds to various stressor gradients at multiple scale, or if a stressor indicator responds to changes in the source emissions.
(4) **How variable is the indicator?** The extent to which natural or introduced variability prohibits detection of the signal through the noise and distorts the description of status or the detection of trends.
(5) **How will the indicator be used?** Demonstrating the indicator in a monitoring or assessment project to determine how it will evaluate condition, vulnerability or the magnitude of stressors.

Research will include both condition and stressor indicators, and the balance will vary depending on the state of science in each area.

- Indicators of Condition—measuring fish, benthic invertebrates, zooplankton, and periphyton communities to determine acute and chronic exposures; and
- Indicators of Stress—measuring patterns of changes in assemblages of organisms or rates of ecological processes to diagnose stressors and to estimate their intensity and relative importance in altering the community composition.

ORD will undertake research in three independent areas:

(1) landscape indicators,
(2) aquatic systems (estuaries, wetlands, rivers/streams, and lakes), and
(3) terrestrial systems.

Approximately 85 to 90% of the total ORD effort will be devoted to the first two areas of research because they are the highest priorities and are the areas in which ORD has the most expertise.

3.2.1.3 Landscape Indicators

Develop ecologically meaningful indicators of current landscape condition and stress and trends related to endpoints of importance to EPA

3.2.1.3.1 Rationale and Objectives

It is becoming increasingly clear that many of the environmental threats today are caused by developmental pressures on the landscape. In many cases, habitat and landscape alterations pose far larger threats to the integrity and sustainability of ecosystems than do pollutants. As a result, ORD has developed a landscape characterization, indicator development, and assessment capability to look, not only at current conditions, but also to document past changes and quantify future ones as well.

The objectives of the landscape indicators research are specified below:

- develop a set of landscape indicators that can be interpreted relative to status and changes in fundamental ecological and hydrologic processes that influence and constrain the sustainability of ecological goods and services valued by society,

Table 3-2. Levels of biological organization to consider during indicator development, with examples of structural and functional aspects of each level.

Structure	Level of Organization	Process
Heterozygosity	Gene	Polyploidy Rate Mutation Rate Recombination Rate
Condition Anomalies/Deformities Maximum Size Tissue Contamination	Individual	Metabolic Rate Growth Rate Fecundity
Abundance Age Class Distribution Size Class Distribution	Population	Reproduction Rate Growth Rate (Population) Death Rate Evolution/Speciation
Relative Abundance Richness, Native Richness, Total Evenness Trophic Composition Reproductive Composition Habitat Guilds	Assemblage (Community)	Competition/Predation Disease/Parasitism Mutualism Recovery Rate
Regional Diversity (gamma) Homogeneity Hot Spots Patches Patterns Fragmentation/Recovery	Watershed or Landscape	Water Delivery Chemical Delivery (Native and Exotic) Material Delivery (Sediment, Wood) Energy Flow Nutrient Cycles and Spiraling Population Sources and Sinks Fragmentation Rate/Recovery Rate

- develop a set of landscape indicators that can be interpreted relative to cumulative stress on areas ranging in size from local communities to regions,
- determine the interrelationship and associations between cumulative stress and landscape conditions at multiple scales, and
- provide guidance to EPA on the measurement and application of landscape indicators.

3.2.1.3.2 Specific Research Foci

The primary emphasis of this research will be on the development and application of approaches to analyze landscape composition and pattern relative to the sustainability of environmental values across scales ranging from local communities to regions. These approaches will take advantage of comprehensive spatial databases that now are available and those being developed. High-resolution, remote-sensing imagery and field data will be used to validate and enhance landscape indicator interpretations. The ability to enhance the interpretation of landscape indicators through collection of finer scale data also may depend on hierarchical relationships among site, landscape, and regional conditions that also will be considered.

Indicators of Human Stress on Landscapes

The primary aim of this research is to relate indicators of human patterns in landscape to exposure profiles (landscape composition and pattern) of indigenous ecosystems, including forests, deserts, grasslands, and prairies, as well as larger systems, including watersheds. Correlations or linkages between human patterns and exposure profiles of landscapes provide a way to evaluate how human settlement in landscapes influence fundamental ecological and hydrological processes, because changes in landscape composition and pattern are coupled tightly to fundamental ecological processes.

Indicators of Landscape Condition and Vulnerability

If landscape composition and pattern indicators are to be used to evaluate the vulnerability of ecosystems at many scales across a region, they must be linked to ecological conditions at one to several scales. Therefore, the following areas of research will be undertaken.

1. ***Habitat Suitability and Landscape-Level Biotic Processes***—Status and changes in landscape composition and pattern have significant consequences for plants, animals, and entire biotic communities, primarily through alteration of the amount and spatial pattern of suitable habitat. Changes in suitable habitat influence landscape-level processes of plant and animal metapopulations, including immigration, emigration, and population sizes; these in turn influence species' vulnerabilities (probabilities) to extinction. The primary aim of this research is to evaluate the degree to which certain landscape indicators co-vary with habitat suitability of species that interact with their environment at different scales. Moreover, the research will determine if critical thresholds exist between landscape indicator values and habitat suitability. If successful, this research will permit an assessment of vulnerability of certain habitats resulting from human-induced changes in the landscape. It also should facilitate an assessment of species extinction probability through the use of landscape indicator input into metapopulation extinction models and assessment of multispecies groups or guilds.
2. ***Water Resources and Hydrologic Processes***—An increasing number of recent studies have suggested that landscape composition and pattern influence water quality, the biological health of streams, and the risk or vulnerability of watersheds to flooding at multiple scales. The primary aim of this research is to evaluate the degree to which indicators of landscape composition and pattern co-vary with the water quality, stream biotic condition, and watershed vulnerability to flooding. An understanding of these relationships permits an assessment of the vulnerability of hydrologic processes to significant impairment resulting from human-induced landscape changes, as well as underlying landscape conditions (e.g., soils, topography) and biophysical processes (e.g., climate). This activity will include research to (1) determine the role of riparian habitat in landscape-water interactions; (2) investigate interactions of landscape features across scales to determine water quality, stream and wetland habitat quality, and the risk of flooding; and (3) evaluate critical threshold values of landscape indicators, with regard to water-related environmental values.
3. ***Terrestrial Productivity***—Status of and change in landscape composition and pattern have direct implications for potential vulnerability of terrestrial ecosystems to losses in productivity, especially in those situations where human pattern and uses influence soil loss. Soil loss reduces the ability of an area to sustain productive forests, rangelands, and prairies. It also results in increased need for fertilizers in agricultural landscapes, which can decrease farm profitability (and hence, farm sustainability), and results in decreased surface and groundwater quality, as well as stream biotic conditions. The primary aim of this research is to develop and test landscape indicators, which, when coupled with soil-loss models, estimate the spatial variability of soil-loss potential within and among watersheds. Within-watershed analysis permits an assessment of the spatial variation of soil loss across a watershed, as well as an assessment of the vulnerability of streams to degradation caused by soil loss. Other indicators, such as changes in the Normalized Difference Vegetation Index, will be

evaluated relative to terrestrial productivity vulnerability. This research also will determine if critical thresholds exist among landscape indicator values, soil loss, and losses in overall productivity.

Effects of Data Properties on Landscape Indicator Interpretation

This research focuses on two areas that can affect the interpretation of landscape indicator values relative to vulnerability analysis.

1. ***Statistical Properties of the Data***—There are a number of properties of landscape data that influence the ability to interpret landscape indicators relative to landscape condition and vulnerability. These properties include the number of samples (in land cover maps, these can vary from a few hundred to several million), the number of attributes (e.g., land cover classes), and the scale dependency. This research will test approaches to reduce losses in interpretative power of landscape indicators resulting from statistical properties of the primary data.
2. ***Sensitivity of Landscape Indicators to Misclassification in the Data***—Interpretability of landscape indicators is influenced by sensitivity of individual indicators to misclassification embedded within land cover and other primary spatial data. Moreover, many landscape indicators are calculated by overlaying different spatial coverages; for example, woody vegetation (land cover data) adjacent to streams (digital line-graph data). This research will develop and test protocols to understand the influence of misclassification of spatial data on landscape indicators.

3.2.1.4 Aquatic Indicators (Estuarine, Wetland, Rivers/Streams, and Lakes)

Develop suites of estuarine, lake, and stream indicators to measure the condition of aquatic resources and the stressors affecting them at multiple scales

3.2.1.4.1 Rationale and Objectives

The traditional focus of EPA has been on aquatic resources, and the ORD research strategy reiterates this priority in its setting of goals for ecosystem protection. Indicators for estuaries, wetlands, rivers/stream, and lakes are in a similar stage of development. The movement toward biocriteria within EPA and the states has pushed the use of biological indicators as tools needed to compliment the existing measures of physical and chemical integrity that have been used traditionally. The objectives of the aquatic indicators research are specifically to

- develop a set of indicators for estuarine, stream and lake systems that can be interpreted relative to status and changes in fundamental ecological and hydrologic processes that influence and constrain the integrity and sustainability of these systems;
- develop a set of aquatic indicators that can be interpreted relative to cumulative stress in areas ranging in size from local communities to regions;
- develop a set of aquatic indicators that can be used to quantify the extent of chemical disturbance, physical habitat alteration, hydrologic alteration, and biological perturbations, such as introduction of exotic species and overstocking/overharvesting;
- determine the interrelationship/associations between primary stressors in aquatic systems (i.e., chemical, hydrologic, habitat, and biological alterations) and aquatic conditions at multiple scales; and
- provide guidance to EPA on the establishment of “expected conditions” for aquatic indicators of condition and stressors.

3.2.1.4.2 Specific Research Foci

Community/Assemblage Level Indicators

The community or assemblage level of biological organization has emerged as the dominant level in which effective indicators of integrity and sustainability are being developed. This suggests that aquatic communities are a good reflection of the cumulative effect of the various stressors to which they are exposed. With a few exceptions, the species have moderate to rather short generation times and, thus, allow identification and reaction to problems before they become irreversible.

Most of the community- or assemblage-level indicators in aquatic systems come from analysis of the fish, benthic invertebrate, or algal communities. The sampling methodologies are reasonably well established, although they require greater quantification as to the amount of variability associated with the sampling process, particularly at multiple scales. Establishment of expected conditions for assemblage-level indicators will consume an extensive amount of the effort in aquatic indicator research. These "expectations" respond to a variety of natural drivers, and these must be accounted for in establishing the indicator. For example, a common metric in fish indices of integrity is species richness. Species richness in lake and stream fish assemblages naturally varies with watershed area. Thus, an indicator with this measure must account for these natural differences. Similarly the benthic community in estuaries varies naturally by substrate type. Without an ability to include consideration of these types of natural drivers, an effective indicator will not be possible.

An added aspect of research on aquatic indicators will be the consideration of the necessary suite of indicators for effective monitoring programs. For example, what is the added value of monitoring the fish assemblage, macroinvertebrate assemblage, and periphyton assemblage? Each community of organisms has different life cycle characteristics and responds to slightly different stressors. This type of sensitivity analysis will be important in developing recommendations for aquatic indicators.

Molecular Indicators

Tools of chemistry and biology are able to be used in the ambient environment to quantify stressor-induced changes at the organismal level and below. Linkages, direct or indirect, continue to be made between stressors and these changes. Directly, chemical stressors may be detected and quantified by their covalent binding to biological macromolecules (e.g., deoxyribonucleic acid [DNA] and protein [hemoglobin] or by the appearance of parent compounds or their metabolites). Indirectly, chemical stressors may be detected by the appearance of induced biochemical structures, lesions, or disease, brought about only by past exposure to specific stressors and occurring only after the progression of a cascade of cellular events. Although these changes may be detected at the molecular level, they may be interpreted at biological levels above that of the organism (e.g., reduced variability in DNA fingerprints of fish may indicate vulnerability of the population to further exposure). Besides the indication of chemical stress, molecular indicators can indicate habitat changes or act as indicators of ecosystem vulnerability (e.g., changes in sediment microbial metabolic activity indicate a vulnerability of the sustainability of stream integrity). Molecular indicators have been developed in the laboratory and are being validated in the field, recognizing the importance of additional sources of variation in the ambient environment.

Areas of research will include

- biochemical indicators—measuring changes cellular processes or structures after stressor exposure;
- toxicological indicators—improving toxicity tests, which parallel the environmental conditions known to exist in areas that are the focus of exposure characterization; and
- genetic indicators—measuring heritable molecular structure of organisms and DNA and its ribonucleic acid (RNA) transcripts present a number of indicator-development opportunities that will be pursued, including
  (1) indicators of genetic toxicity,
  (2) changes in the level of specific gene expression, and
  (3) fingerprinting DNA.

Biochemical Indicators—Changes can be detected in cellular processes or structures after stressor exposure. The sequence of binding, either direct (covalent abducts) or through messengers (e.g., receptor mediated) act as indicators of specific chemical interaction in a biological compartment. Changes in endogenous cellular metabolite levels (e.g., glutathione) indicate exposure to properties of chemicals (e.g., oxidative stress). Biochemical indicators have been developed for several classes of chemicals (e.g., induction of the liver metabolic enzyme cytochrome P450IA1 by polycyclic aromatic hydrocarbons

(PAHs), formation of DNA and protein covalent abducts by alkylating agents [carcinogens], changes in liver gene expression by estrogen agonists and antagonists, and induction of metal-binding proteins by metals.) Significant advances in the basic biochemical sciences are providing new tools with greater specificity and sensitivity for the detection of biotic and abiotic stressors.

Some biochemical indicators are at the early stage of development, whereas others already are being used in vulnerability studies. Those in the early phase of development include modification of off-the-shelf antibody detection systems to measure polychlorinated biphenyl (PCB) concentrations in fish tissues and measurements of pesticides. Some that are being field validated include PAH metabolites and metabolic enzymes (EROD), which are being field validated in the Mid-West and Mid-Atlantic regions.

Genetic Indicators—The heritable molecular structure of organisms, DNA and its RNA transcripts, present a number of potential indicators that leave clues to the stressors to which the organism has been exposed.

- Indicators of genetic toxicity, evaluated at three levels—(1) nucleotide changes, (2) chromosomal structural changes, and (3) chromosome number changes—have been used to detect mutagens and carcinogens in both fish and terrestrial mammals. Research on the "single-cell gel electrophoresis assay" in fish, mammals, and macroinvertebrates will enhance the detection limits for induced DNA damage in a variety of tissues.
- Changes in the level of specific gene expression—vitellogenin, P450IA1, metallothionein—have been used to detect estrogenic xenobiotics, PAHs, and metals, respectively. Research using quantitative reverse-transcription PCR will allow the use of multiple probes of altered gene expression.
- DNA is being analyzed with fingerprint techniques to characterize the degree of heterozygosity as an indicator of genetic diversity in populations of fish and terrestrial mammals. For this, research on the use of single locus PCR will allow a more robust characterization of population heterozygosity.

3.2.1.5 Terrestrial Indicators

Develop indicators of forest condition and stress as affected by ozone, global change, and other air pollutants

3.2.1.5.1 Rationale and Objectives

Although forests have been monitored for resource use, such as timber production and wildlife habitat, the ability to measure change in forest ecosystems in a timely manner for use in developing and assessing emerging environmental policy still is not perfected. Commonly used plant indicators, such as canopy damage or growth, are species- or resource-specific and, because of the longevity of the species, may not show a response in time to address the problems when found.

The following are ORD goals for terrestrial indicator research.

- Develop reliable, scientifically defensible indicators for measuring change, specifically indicators of ecosystem stability or integrity.
- Develop a "theoretical basis" from which predictions can be made of general types of forest response to different types of stress.
- Develop indicators that are responsive to regional stresses such as tropospheric ozone, climate change, and land use.

3.2.1.5.2 Specific Research Foci

Plants are very well adapted to changing environments, including nutrient and water availability, insect predation, and even atmospheric pollutants as long as the rate of stress does not overcome the individual's ability to adjust carbon, nutrient, and water processes. Because of this ability to adjust, vegetation indicators should be physiologically based and should measure the plant's ability to integrate and assimilate across its environment. Failure to integrate its environment is a signal that the vegetation is under stress. Two critical processes from which indicators may be developed demonstrate this adaptability: (1) alteration in the allocation of carbohydrate and (2) decreased water-use efficiency. Research will focus on rhizosphere and ecosystem process measures.

The efficiency with which water is used by the plant to fix carbon is another process from which possible indicators may be developed. Under ozone exposure, both annual crop plants and tree seedlings have been observed to have reduced water-use efficiencies. It takes more water to fix a gram of carbon under ozone than in clean air. This suggests that the plant is not integrating its environment appropriately.

3.2.1.5.3 Implementation

As described above, the research on indicators in ORD will be achieved via in-house capabilities and through the extramural grants program. The ORD Indicator Research Plan will outline in detail the specific indicators that ORD will undertake and which areas will be sent to the external research community for development.

3.2.1.6 Government Performance and Results Act Milestones

- **By 2002**, provide indicators of habitat suitability, landscape-level biotic processes, water resources and hydrologic processes, and terrestrial productivity for measuring the vulnerability of multiscale landscapes to change as a result of climate change and other stressors.
- **By 2003**, develop, apply, and evaluate the next generation of biological indicators that are most applicable to measure the success of water quality policies on freshwater and estuarine system condition and issue recommendations for their use and interpretation.

3.2.2 New Technologies and Chemical Measures

Government Performance and Results Act Subobjective:
Implement systems to deliver reliable, timely, and consistent environmental monitoring and measurement information to the public and communities and deliver data and information to multiple users, with multiple needs, in real time for decision making

3.2.2.1 Background

It became apparent very early on that EPA needed a capability to not only identify, measure, monitor, and clean up contaminants that impact the environment, but also to assess the impact of human activities on their surroundings. The development and application of monitoring and measurement technologies has progressed, but there is a general sense that more progress should have been made.

To date, EPA has spent much of its technology research and development efforts investigating the application of devices for measuring discrete points in complex hydrological, geological, and ecological settings. EPA, in partnership with other federal and state organizations, is seeking to identify, adopt, and apply innovative monitoring technologies to provide more timely, accurate, comprehensive, and cost-effective monitors for measuring releases to the environment. The Advanced Measurement Initiative (AMI) supports EPA's mission to develop new, advanced monitoring technology. AMI is designed to accelerate the application of advanced technologies for environmental monitoring and measurement, as well as move EPA towards a more coherent multimedia approach to environmental monitoring, and it is one of the programs supporting this area of research.

The research includes development and application of methods for a variety of environmental parameters, some that are now capable of providing continuous, real-time data from remote locations, and others that permit quantitative measurement of phenomena that, in the past, have been impossible to measure. In addition, rapid developments in instrumentation and methodologies are significantly improving detection limits for many chemical species and making measurements more accurate, faster, and less expensive.

Therefore, central to the collection of all research in this area is a common set of elements and criteria that serves as the road map for development. Any one of these elements can serve as the focal point for research. However, it is the collection of these components that constitutes the most effective new techniques and methods.

Communication—The communication element addresses effective transfer and display of information to the user (e.g., research modelers, the public, or surveillance monitoring agents). This element addresses information distribution, public outreach, technical transfer, and educational aspects of needed technology and will rely on and support the visualization and modeling capabilities of ORD. The long-term goal for this element is to develop capabilities for real-time and self-correcting models and accompanying visualizations that will communicate monitoring information in real or relevant time to a range of user needs.

- **Data Management**—To meet multiple user needs, effective and timely access and distribution of information are critical. An information management system, built on existing EPA and interagency approaches will be designed to manage and distribute data.
- **Data Processing and Analyses**—As with measurements, specific data processing and analysis needs are a function of specific monitoring objectives. Overall goals will emphasize capability for real- or relevant-time processing solutions.
- **Telecommunications**—Delivering information from the collection site to the user more quickly and efficiently is an important consideration of future monitoring efforts. Guidance for telecommunications options and solutions, therefore, will become part of the program to ensure interoperability with states and other federal agencies. The goal of the telecommunications element is to provide the users with real- or relevant-time relay of measurement data and information.
- **Measurement**—Measurement solutions and techniques are a function of specific monitoring needs or parameters (i.e., ozone, UV-B, tree height). This is the area where ORD might make its most significant contribution. However, the measurement methods and systems developed will be driven by user needs. Partnerships with those with advanced technologies will be an important consideration in this element, and the development of spatial and temporal sampling methods that will drive measurement location and timing will be one focal point of the effort.

Considering these elements as the guiding principles, the two primary elements of this research program are listed below.

(1) **Environmental Chemistry**—Knowing the presence and concentration of the toxic form of pollutants is a challenge to modern analytical chemistry. Pollutants often occur in multiple forms, some of which are much more toxic than others (e.g., mercury). Some pollutants are toxic at extremely low levels (e.g., dioxins). Therefore, specificity and low detection limits are needed to improve risk assessments. Therefore, the goal of this research is to develop methods for measuring biologically and ecologically important chemical pollutants, their transformation products, and chemical indicators of exposure to stressors.

(2) **Environmental Characterization Technologies**—New technologies (faster, more precise, and less expensive) are essential to improving the delivery of data and information to all parties. Therefore, the goal of this research is to develop, evaluate, apply, and validate multimedia environmental characterization and monitoring methods and technologies.

3.2.2.2 Environmental Chemistry

Develop methods for measuring biologically and ecologically important chemical pollutants, their transformation products, and chemical indicators of exposure to stressors

3.2.2.2.1 Rationale and Objectives

Environmental chemistry is an important element of ecological research for three primary reasons. First, adverse effects of anthropogenic chemicals continue to emerge (e.g., endocrine disruption). Second, biotic and abiotic processes in the environment transform stressors, sometimes into even more toxic species (e.g., methylmercury). Third, chemicals that are not themselves stressors can be indicators of exposure to both chemical and nonchemical stressors (e.g., serum vitellogenin in fish as an indicator of endocrine disruptor exposure). Existing measurement methods were developed to support regulations with acute toxicity or carcinogenicity as end points of concern. Stressors that produce effects such as reduced reproductive success often are not measurable by extant analytical methods, or current methods lack the required sensitivity or are too slow or costly for routine application. Measurement methods for transformation products of stressors or indicators of exposure usually do not exist. This research element will, therefore, provide the analytical methods needed to improve chemical characterization of multiple media.

This research element will not just develop measurement methods, it will integrate them into complete environmental analytical approaches with guidance that will ensure appropriate use and data interpretation. All research in the chemical methods area will consider all aspects of the elements outlined in the earlier section.

Specifically, the research in this area will

- identify gaps in chemistry knowledge and limitations in analytical capabilities that impact ecological research;
- develop methods with sufficiently low detection limits to establish "native" backgrounds and to provide early warning and long-range indication of exposure, measure relevant levels of pollutants that bioaccumulate, and evaluate chronic and synergistic multiple chemical exposure, among others;
- apply new chemical measurement methods to intensive long-term monitoring of selected index sites, with the aim of establishing baselines and trends for both known (target) and occult (nontarget) chemical stressors; and
- conduct hypothesis-driven research that requires specialized environmental chemistry approaches to address questions regarding environmental processes influencing exposure to chemical stressors.

3.2.2.2.2 Specific Research Foci

Method Development

Analyses will be prioritized based on the extent to which the method development effort will impact the uncertainty of the exposure risk of some valued ecological resource to a significant chemical stressor. For example, little currently is known about the extent and importance of exposure of fish to estrogen mimics. The development of a universal serum vitellogenin (estrogen-induced protein) assay for all species could prove to be a very high-priority analysis (in this example, the analyte itself is not the stressor). Whenever possible, this activity area will apply both inexpensive field-portable instruments and methods. However, the demanding analyses required to meet many of the stated objectives can only be performed using sophisticated laboratory instrumental approaches. In either case, the research will encompass the entire analytical protocol, from sampling design and methodology to data interpretation and presentation. Once appropriate methods are produced and validated, they will be field-tested in the index-site monitoring program, and refinements will be made before publication.

The primary objectives of this research will be to

- develop advanced sample cleanup, extraction, and separation methods that will enable measurement of stressors, their transformation products, and indicators in complex multimedia samples, including sediments, soils, and biological tissues and fluids;
- produce chemical measurement methods that are rapid and cost-effective, so that sufficient numbers of multimedia samples can be practically analyzed to provide statistically defensible conclusions;
- develop methods to measure chemical stressors in the form most relevant to ecological processes, including biochemically active enantiomers and the most toxic and mobile species of arsenic, tin, mercury, and selenium;

- provide methods of sufficient detection power to allow accurate measurement of baseline concentrations of stressors in nonimpacted ecosystems;
- develop approaches to measuring nonvolatile stressors, which often make up the most toxic fraction of sediments; and
- produce methods for chemically measuring macromolecules, such as proteins and hormones, that indicate exposure to stressors.

Method Application

The primary objectives of this research are to

- provide field testing of chemical measurement approaches produced by the program;
- conduct long-term monitoring of selected index sites, with the aim of establishing baselines and trends for both known and occult chemical stressors; and
- conduct hypothesis-driven research that requires specialized environmental chemistry approaches to address questions regarding environmental processes influencing exposure to chemical stressors.

The research in this area will be initiated with a chemical screening of deposition, surface water, sediments, soils, and selected biota at EMAP Index Sites (see Section 5). This screening will include quantification of target stressors, again prioritized by the probable impact that stressor distribution baseline and trend data would have on uncertainty of ecological risk. The research also will characterize nontarget chemicals based on chromatographic retention time and response profiles. Potentially significant nontarget compounds then will be selected based on significant apparent concentration (from response), presence of heteroatoms (from selective-detector response), and frequency of occurrence. The nontarget compounds will be identified and quantitated by mass spectrometry and other means, and these will become target compounds in subsequent rounds of the program. The specifics of the sampling, sample preparation, and analysis protocol will be the focus of extensive method development in FY98.

The hypothesis-driven research will focus on field studies conducted in conjunction with the long-term monitoring effort, although some supporting laboratory work also will be performed. The research will address the physical, chemical, and biological processes affecting transport and fate of stressors and exposure of receptors. It also may test hypotheses concerning optimal monitoring approaches. For example, the feasibility of various approaches to efficiently provide stressor distributions at multiple spatial and temporal scales will be tested. In addition, exposure indicators will be evaluated as part of this research.

Finally, the approach for the long-term monitoring of important stressors will be developed. Although method development continues on the prioritized stressor list that will be finalized in late 1997 and on method gaps identified in the development of long-term monitoring strategy, the long-term monitoring program will be applied in a pilot study at one or two index sites. The results of that study, as well as those of the early hypothesis-driven research and continued method development, will be used to refine the approach for use at more sites. This will be an iterative process. Although a core of high-priority target stressors, media, and sites is maintained, the remaining scope and emphasis areas of the program will change as previous data is analyzed. A preliminary report on trends in stressors will be prepared in FY05.

3.2.2.3 Environmental Characterization Technologies

Develop, evaluate, apply, and validate multimedia environmental characterization and monitoring methods and technologies

3.2.2.3.1 Rationale and Objectives

One of ORD's missions is to perform research and development activities that identify, understand, and solve current and future environmental problems. To fulfill this mission, it is essential to develop scientifically sound approaches to provide cost-effective, accurate approaches for the determination of parameters of interest. Environmental characterization technology research involves the development and use of new, innovative, cutting-edge techniques and tools that will allow scientists and decision-makers to confidently and accurately identify the hazards or stressors of the environment and to understand the ecosystem as a whole, rather than just individual pieces. The development of the environmental characterization technologies is divided into several phases, namely, development, evaluation, application, and validation of new methods and technologies. Each of these phases is important to provide EPA with the best available techniques and methods to meet the constantly changing demands of newly identified or suspected environmental and health stressors.

Specifically, the objectives of this research are to

- identify major knowledge and technology gaps that currently are limiting the effectiveness of EPA to accurately, rapidly, and cost-effectively characterize and monitor the environment;
- conduct research to more fully understand *all* the processes associated with a given environmental problem across all media including air, surface water, groundwaters, soils, sediments, etc. (i.e., a multi-media environmental approach) (Research will be conducted in areas that include the assessment of the planning, sampling, sample preparation, and analysis.);
- identify and assess the performance of innovative and alternative technologies potentially useful for rapid, reliable, and cost-effective characterization and monitoring;
- where existing technologies are either lacking or inadequate, develop and evaluate new cost-effective technologies and approaches for surface and subsurface characterization and monitoring;
- develop user-friendly guidance documents for site characterization strategies and monitoring methods; and
- facilitate the development of innovative monitoring tools and approaches that can be utilized in the next century, and that will help move EPA towards a more integrated, multimedia environmental protection program.

3.2.2.3.2 Specific Research Foci

Research in the area of environmental characterization technologies will take a multipronged approach because of the diversity of the current (and future) environmental problems that need to be solved; the diverse aspects involved in producing/developing acceptable, scientifically sound approaches and technologies to the problems; and the necessity to characterize and monitor all media, rather than focusing on any one individual medium. Several specific areas of research that will be conducted include environmental characterization technologies and technology verification.

Environmental Characterization Technologies

Research will focus on all aspects of data generation, ranging from sampling through analysis and, finally, to data interpretation. Improved methods for the collection of soil, groundwater, and surface water samples is essential for the proper characterization and monitoring of the environment. This work not only will involve development and testing of improved sampling devices and techniques but will also emphasize where and when to collect the samples to allow for valid interpretations to be made in the complex multimedia situation. Once the proper number and locations of the sampling sites have been identified, the next phase is to collect the data of interest. Research in this area will involve the development and testing of rapid, field-portable methods for characterizing the soils, groundwaters, and surface waters. The goals of these techniques will be cost-effectiveness, accuracy, preciseness, and ease of use. The development of nonintrusive techniques, where possible, also will be explored to minimize "damage" to the environment that may be associated with the commonly employed intrusive techniques. These techniques should be capable of determining the parameters of interest in both "clean" environments for ecological monitoring programs as well as at contaminated waste sites for contaminant detection, evaluation of remediation activities, and decision support for exposure/risk assessment and site management activities. Once the data is generated, valid statistical methods for data interpretation are needed. Research will be conducted to provide valid techniques: assess mapping of the parameters of concern, assess the statistical validity/usefulness of the data, and determine how to deal with outlier data.

Guidance documents for all these aspects will be developed in a user-friendly format, to allow for better and more accurate surveys to be conducted. Both grant-based and remotely sensed techniques will be pursued.

Subsurface Characterization—Development and evaluation of surface-based, noninvasive, geophysical techniques to delineate, characterize, and monitor movement of contaminant plumes in the subsurface/groundwater environment. Research currently is being conducted towards the detection and quantification of dense and light, nonaqueous phase liquids (DNAPLs and LNAPLs), which generally are associated with leaking underground storage tanks or solvent abuse at hazardous waste sites. Future directions in this research area will include using these technologies to monitor and asses the effectiveness of natural attenuation remedial actions, to determine the effectiveness of containment barriers to prevent contaminant spread, and to evaluate the effectiveness of sensors, monitor well designs, and monitor network designs, as related to movement of contaminants in the subsurface.

Field Sampling Methods—Development of scientifically sound approaches to assessing and characterizing risks to human health and the environment resulting from improper sample collection and handling techniques and to provide state-of-the-science methods and guidance on how to properly collect the samples. Research currently is being conducted on improving the sampling of soils for volatile organic compounds (VOCs), on examining the leading particulate sampling theory for reducing errors associated with all forms of sampling, and on developing enhanced performance methods for the improved interpretation of generated data. Future directions in this research area will include development of an improved sampling device for VOC-contaminated soils, improved understanding of the factors that influence VOC reactions in soil and waters, real-world testing of the leading particulate sampling theory to validate its effectiveness versus costs, and development and assessment of robust statistical techniques to improve data quality and subsequent data interpretation.

Sampling Design—Develop, test, and validate various strategies and computer algorithms for improving the cost-effectiveness of the sampling/estimation/decision process in characterizing and remediating contaminated soils and other solid wastes, improving sampling design, and interpreting data by using geostatistics. Research currently is being conducted to combine all aspects of the data quality process to environmental research, to support the development of the hazardous waste identification rule (HWIR), and to develop and combine available and innovative statistical and geostatistical tools/techniques in a single, user-friendly software program. Future directions in this research area will include developing innovative sampling design optimization techniques; providing improved guidance that integrates all aspects of the decision-making process; and producing easy-to-use software packages that help the site investigator make appropriate choices, given site-specific decision performance requirements.

Demonstration and Verification of Field Monitoring and Characterization Technologies—Identify and assess, then demonstrate and disseminate information about innovative and alternative environmental monitoring, measurement, and characterization technologies to developers, site managers, and regulators. Research in this area is being performed under two distinct programs, namely, the Advanced Measurement Initiative (AMI) and the Environmental Technology Verification (ETV) programs. AMI currently is sponsoring projects in the areas of remote spectrometry for characterizing hazardous and mining waste sites, deployment of remote air emission monitors for industrial facilities, and development of data management and presentation tools. Demonstrations currently being conducted under the auspices of the ETV program include sampling devices for VOCs in soil, PCB analyzers, decision support software, and on-site and remote air emission monitors. Future initiatives and demonstrations for these programs will include VOC samplers for groundwaters; air emission monitors for water, soil, and industrial process systems; geophysical methods; and other areas as innovative technologies are developed and identified.

Monitoring and Characterization Technical Support—Provide site-specific technical support for complex contaminant characterization projects. The Technology Support Center (TSC) for monitoring and site characterization provides and implements cost- and time-effective technologies for identifying the levels and geographical extent of contaminants and for determining contaminant speciation for risk and exposure assessment purposes. Specific projects are established by requests from EPA program offices and regions. The TSC will continue to support the program offices and regions for future directions, as requests are received.

Remote Sensing Applications—Develop remote sensing techniques to support risk assessments, particularly in support of the landscape research program. Research will focus on (1) application of remote sensing technology to generate new landscape indicators; (2) development of methods to calibrate indicators derived from remote sensing to field or site conditions; (3) development of landscape and ecological process indicators that are derived from raw spectral data (e.g., Normalized Difference Vegetation Index), which relate to ecosystem vulnerability; and (4) development of methods that take advantage of multiple remote sensing data (e.g., radar and land cover), including data from new instruments, to detect important landscape features (e.g., wetlands). The program also will maintain a remote sensing capability in the areas of data acquisition and archiving, analysis and processing, and mapping to support the ORD ecology program and to ensure that the program has access to and use of multiscale and multispectral remote sensing data needed to perform landscape research.

Environmental Technology Verification

EPA has instituted a new program, ETV, to verify the performance of innovative technical solutions to problems that threaten human health or the environment. Managed as part of the President's Environmental Technology Initiative by EPA's ORD, ETV was created to substantially accelerate the entrance of new environmental technologies into the domestic and international marketplace. ETV will supply technology buyers, innovation developers, consulting engineers, states, and EPA regions with high-quality data on the performance of new technologies. This approach will allow more rapid protection of the environment through better and less expensive approaches.

ETV has begun with several pilot projects that will draw on the expertise of partner organizations to design efficient processes for conducting tests of new technologies with EPA oversight. Partners are selected from both the public and private sectors, including federal laboratories, states, universities, and private sector facilities, to perform and report verification activities based on testing and quality assurance protocols developed with input from all major stakeholder/customer groups.

There are 12 verification pilot projects being operated under the aegis of ETV:

(1) Indoor Air Products,
(2) Small Drinking Water Treatment Systems,
(3) Characterization and Monitoring Technologies,
(4) Advanced Monitoring Systems,
(5) Source Water Protection,
(6) Metal Finishing,
(7) Pollution Prevention and Waste Treatment Systems,
(8) Pollution Prevention/Innovative Coatings and Coating Equipment,
(9) Wet Weather Flow,
(10) Air Pollution Control,
(11) Climate Change, and
(12) Independent Entity.

Two pilots of particular interest to the ecological research program are the Site Characterization and Monitoring Technologies and the Advanced Monitoring Systems. The Site Characterization and Monitoring Technologies pilot began in the spring of 1995 and has verified 11 innovative technologies, including two cone-penetrometer-deployed sensors, two field-portable gas chromatograph/mass spectrometers, and seven field portable X-ray fluorescence analyzers. Technologies currently being verified include VOC sampling devices for soil; other sampling devices for groundwater, soil, air, soil gas; PCB analyzers; and decision support software. The Advanced Monitoring Systems pilot has just been initiated. The technology types to be verified in this pilot program will include on-site and remote monitors, with initial focus on air emissions. Water, soil, and process monitors will follow in out years.

The ETV program (*Environmental Technology Verification Program: Verification Strategy*, EPA/600/K-96/003), gradually will expand to cover all appropriate environmental areas. The 12 pilot project areas defined currently are expected to evolve and, in some cases, shift to other areas of need or importance. It also is expected that by the year 2000, 50 technologies per year will be verified, with verification levels tapering off to about 35 technologies per year.

3.2.2.4 Implementation

Most of the environmental chemistry work will be conducted by in-house scientists. However, because most technology advancements are made within the private sector, most of the characterization technologies are developed by others, although not exclusively, and tested by in-house scientists (e.g., the ETV program). Statistical approaches to sampling and applications of remote sensing technologies to landscape characterization will be done by both by in-house scientists and through the grants program as the specific needs become clearer.

3.2.2.5 Government Performance and Results Act Milestones

- **By 1999**, identify existing and emerging technologies to provide capability for gathering and managing real-time environmental monitoring and modeling information.
- **By 1999**, begin a long-term screening program for determining chemical pollutants present in EMAP background site biota, water, air, and soil.
- **By 2000**, provide ETV verification reports and data to the public via Internet, community outreach, and technology transfer for 50 environmental technologies.
- **By 2003**, develop operational advanced monitoring technologies for remotely sensed data on ambient air, water and water quality, and ecosystem characteristics.
- **By 2005**, establish a fully operational environmental technology verification program as a public-private sector partnership, as warranted by ETV pilots and verification results.
- **By 2005**, develop advanced measurement, computing, modeling, and data management technologies, and integrate them into an effective system for real-time delivery of multimedia, multipollutant information on environmental status and risk.

3.2.3 Monitoring Design Research

Developing multiscale monitoring designs and statistical techniques for monitoring the current conditions and trends in the condition and exposure of the nations ecological resources

3.2.3.1 Background

It is clear that monitoring cannot be done on everything, everywhere, all the time. Historically, monitoring has focused on individual locations because of interest in that particular site, a point source discharge location or high-priority resource. In doing so, however, seldom has serious thought been given to how well the signal of environmental disturbance to identify a change, if it occurs, can be detected. Even more uncertain are monitoring approaches for evaluating the condition of large geographic portions of the country. In addition to indicator development, serious attention must be given to the design of monitoring approaches that can describe the status of large regions and actually allow the detection of changes and trends. Research in monitoring will range from the fundamental elements of taking measurements at the local scale to the designs necessary for describing status and detecting trends over large geographic areas. Monitoring research will culminate in regional and national demonstrations that bring into focus the results of indicator development, technology development, monitoring design research, and process understanding research and apply them in regional assessments.

Most monitoring systems begin with “plot” measurements, (i.e., the measurements or samples taken at a particular point in the environment). The plot measurement design is closely linked with the development of the particular “indicator” and the scale at which it is appropriate. This variously has been referred to as the “plot-scale” protocol or the “response” design or “site” measurement design. It ranges from how one chooses to represent and sample a particular point (e.g., such as an air sample for chemical analysis), a small area of a resource (e.g., a stream “reach”) or a different scale (e.g., a landscape viewed through remote imagery). Examples would be the plot design one uses to collect an effective representation of the fish assemblage structure within a stream or the design one uses to collect “wet” and “dry” deposition at a location or a sample of chemical contaminants in soil from a site.

A second element of monitoring systems design research relates to the way in which samples from multiple plots are aggregated for an assessment across a broader geographical area. This still may depend on the scale of the question of interest. For example, it may be of interest to characterize the extent and magnitude of soil contamination within a Superfund site that is still a relatively local scale, or the question may relate to the best design to use for selecting stream reaches to sample when the end result is supposed to be aggregated to answer questions about the length of stream that is impacted within a state or EPA region.

Whatever the scale of interest, it is important to consider the entire “monitoring process” as the system of interest. Variability, which will ultimately impact the assessment process, can be introduced at several levels, starting with the design process itself (uncertainty in the source information used to develop the design [e.g., maps of stream reaches]), and including the sampling (temporal and spatial variability at the sample location, crew errors, variability in implementing the field protocols), the sample processing and analysis (variability in analytical methods, variability in identification of biota), the sample aggregation process (combining data from multiple locations [e.g., a random sample from all possible streams that could have been sampled]), and the data analysis phase.

Within ORD, EMAP serves as the primary focal point for ecological monitoring research (see Section 5). EMAP is an ORD-wide program geared toward providing improved monitoring capabilities for regional and national scale assessment questions. The research on monitoring designs required to make EMAP successful are developed in more detail in the 1997 EMAP research plan.

3.2.3.2 Ecological Monitoring Research

3.2.3.2.1 Rationale and Objectives

CENR has proposed a national monitoring framework that recognizes the importance of different approaches to monitoring from intensively studied, hand-selected sites; to regional and national probability surveys; and finally to remote sensing, where essentially a complete census can be derived. The most significant aspect of this framework is that remote sensing, regional surveys, and site-specific monitoring should be conducted in a coordinated fashion, allowing the full range of integration that so far has been impossible. All three types of monitoring identified are essential for an integrated environmental monitoring capability. Although key elements of the CENR framework can be put into place now, additional research will be required before complete implementation is possible. Within each of the three tiers described, research must be conducted at appropriate scales to improve survey and monitoring methods, to understand the ability to detect and interpret meaningful changes that are observed, and to link these results in the development of descriptive or predictive models. Research on the ability to determine cause and effect must integrate information on processes that occur across the range of scales, from large regions to individual sites. Additionally, methods of designing each of these approaches must be explored, such that they can be integrated and allow additional information to emerge that otherwise might not be available. ORD already has demonstrated this through a monitoring approach for detecting trends in aquatic systems that are sensitive to acidic deposition. This type of research must be extended to other systems and to other types of stressors.

Specific objectives within this research are to

- develop plot-scale designs for effective local monitoring, describing status and detecting trends in local conditions;
- develop survey designs for describing status and trends in regional populations of lakes, streams/rivers, wetlands, estuaries, and landscapes; and

- develop a process for determining the power of specific designs for detecting trends of varying magnitudes.

3.2.3.2.2 Specific Research Foci

Atmospheric Monitoring—Increasingly, the chemical contaminants that were entering the biosphere via point sources are now being introduced via non-point source emissions. This term, "non-point source emissions", was for a period synonymous with the distributed introduction of chemicals overland into our water resources. More recently, ORD has become increasingly aware that many chemicals also are being introduced to the atmosphere and being transported locally and globally. They are returned to aquatic and terrestrial systems via deposition, both wet and dry. Research will focus on dry deposition estimation of nitrogen and sulfur, UV-B monitoring, and improvements in air toxics, ozone, and metals monitoring.

Soil and Sediment Monitoring—Soils and sediments represent a three-dimensional matrix that is extremely heterogeneous in each of its dimensions. As concerns increase about the safety of water supplies in aquifers; the storage of contaminants in sediments of lakes, rivers, and estuaries; and the viability of soils for future production, it becomes more important to improve the ability to characterize this multidimensional matrix.

Aquatic Systems Monitoring—Extensive work has been devoted to the ability to characterize small streams that dominate the landscape in terms of their length and distribution. Significant advances in the ability to monitor chemical, physical, and biological quality of these systems have been made. However, relatively little attention has been paid to larger riverine systems, or how best to characterize any specific segment of a large system from a chemical, physical, or biological perspective. Given the reliance on these systems for commercial fisheries, drinking water supplies, and navigation sources, this state of knowledge must be improved.

Survey designs that can be applied to extensive aquatic resources, such as wetlands and estuaries, are also a priority area for research. The local variability within these systems, as well as the population or regional level of variability, is poorly understood. Quantification of variability is essential before future designs can be recommended confidently; therefore, this will be the focus of the research effort.

Landscape Monitoring and Characterization—The ability to extract information about landscapes and broad geographic regions from the spectral signals derived from satellites is in its infancy.

Landscape characterization documents the composition and spatial relationships (patterns) of ecological resources, including forests, streams, estuaries, urban environments, and agricultural and rangelands, over a range of scales, as it relates to ecological condition and resource sustainability. The approach also considers the spatial pattern of other biophysical attributes, including geology, climate, topography, hydrology, and soils, because they often influence or determine landscape composition and pattern and the sensitivity of ecological resources to stressors within any given area. The goal of this research and coordination will be to develop comprehensive, consistent databases of the nation's landscapes, resources, and physical features at multiple spatial and temporal scales. The primary objectives of this element of the program are as follows:

- the acquisition of land cover data at multiple scales to support both the Ecological Research Program and EPA as a whole, including classification and labeling research, accuracy assessment research, and classification and labeling implementation; and
- documentation of past and future changes in land cover, including monitoring changes in the land surface, understanding the processes that influence the land surface, and forecasting land surface response.

3.2.3.3 Integration of Monitoring Approaches

3.2.3.3.1 Rationale and Objectives

Given the increased importance of understanding management actions over broad geographic regions, improved network design is a major research issue. Monitoring designs most often are directed at rather narrowly defined problems and are seldom explicit in terms of quantifying bias, predictive power, or value to a concept for holistic risk assessment. In the United States, there are dozens of intensive study sites and hundreds of specialized monitoring sites nationwide with no unifying scientific concept to integrate data. Monitoring data often cannot be aggregated to answer larger questions.

Specifically, the following will be objectives of this research:

- develop approaches for integrating different types of monitoring, including probability surveys, remote sensing, and data from hand-selected sites;
- estimate, on a regional basis, with known confidence, the status, changes, and trends in land cover;
- estimate, on a regional basis, with known confidence, the status, changes, and trends in the condition of estuaries, streams/rivers, and wetlands;
- estimate, on a regional basis, with known confidence, the status, changes, and trends in the condition of landscapes; and
- seek associations between indicators of condition in aquatic resources and landscapes and indicators of natural and anthropogenic stressors.

3.2.3.3.2 Specific Research Foci

ORD will stimulate an effort aimed at improving multitier designs and engaging design specialists in all agencies for their essential participation. Key in this research area will be the evaluation of the role of sample surveys (statistical or probability-based surveys) in characterizing ambient stressor and condition information, both for estimates of status (current situation) and trends.

Within terrestrial monitoring agencies, sample surveys are a standard operational tool. Within the aquatic monitoring agencies, sample surveys are almost unheard of as a standard tool. The historic reasons for this are important. Traditionally monitored aspects of terrestrial systems that are of economic importance have been the primary focus (e.g., crop production, availability of timber for harvest). Historically, rigorous statistical estimation has been relied on when financial resources are of concern, hence the use of rigorous surveys. Aquatic systems have not been viewed from the same perspective, in spite of their obvious economic importance. Additionally, aquatic monitoring comes predominantly from a background of concern about point source discharges of pollution. This naturally leads to more localized designs and an upstream/downstream monitoring perspective. As the importance of non-point source pollution and other stressors to aquatic systems, as well as the geographic breadth of concerns, is better understood, more applicable monitoring network designs must be developed.

This area of research will focus on advancing the understanding of survey designs for monitoring inland aquatic, estuarine, and wetland resources, as well as landscapes. The options available for monitoring status and trends, or blending the needs of both, will be evaluated. The concern also will extend to differences in survey design approaches for extensive resources such as estuaries, linear systems such as streams, discrete resources such as lakes, and wetland systems that have elements of each of the above characteristics.

The Mid-Atlantic region will serve as the first demonstration project for pulling these monitoring efforts for aquatic resources and landscapes together in conjunction with indicators of stressors that may be impacting these systems.

In support of integration, there will be an expanded environmental statistics research program. There are very specific aspects of environmental statistics that require research for improving monitoring capabilities. At the interface of indicators and monitoring design is the need to develop a process or framework for measuring, describing, and understanding the dimensions of variability. In some cases, the monitoring system can be designed to minimize the extraneous or introduced variability; in other instances, such as natural dimensions of variability, it cannot be minimized, but it can be described so that how it clouds the ability to describe status and detect trends can be understood. This area of research will require extensive evaluation of indicators over broad geographic regions, as well as temporally within and across years. The variability analyses that results from these data then will be brought to bear on evaluating monitoring design options for programs being developed within ORD and other parts of EPA and by the states. Research will include the areas described below.

- The development of designs and composite estimators for surveys over time, should lead to improved efficiency of estimation and, hence, to reduction of cost for conducting large-scale status and trend monitoring.
- Statistical models that improve the spatial-temporal linkages of information from intensively monitored, hand-selected networks and probability surveys have received little attention to date and will be a key focus of research on streams in the Mid-Atlantic region.
- Accuracy assessments of remotely sensed data for evaluating the reliability of monitoring changes in land cover and landscapes will be conducted.
- Methods for analysis of massive data sets from remote sensing platforms must be developed to reduce the time between acquisition of data from the satellite and availability of product. Given that changes in land cover are among the most significant stressors in impacting ecological resources, the length of this delay must be resolved soon.
- Statistics research focuses cover regions; development of new data analysis tools will help describe, understand, and interpret environmental data over large regions and capture its critical spatial characteristics.

3.2.3.4 Implementation

ORD will commit to developing sampling designs for monitoring status and trends in aquatic systems and landscapes. These designs will be tested with the most effective indicators in regional geographic initiatives within EMAP, and the resulting data will be used in regional risk assessments. ORD will utilize in-house expertise to design these regional monitoring studies and utilize extramural resources to contract the collection of the field data. The land cover generation will be a federal interagency partnership, and some survey design evaluations and studies of variability will be conducted through the grants program.

3.2.3.5 Government Performance and Results Act Milestones

- **By 2000**, make publicly available digital, land cover data for a baseline period (1990 to 1993) and all regions from which changes in land cover can be accurately and quantitatively documented.
- **By 2001**, complete an evaluation of a multitiered, ecological monitoring system for the Mid-Atlantic region of the United States and its applicability to other areas of the country.
- **By 2002**, publish a design and guidelines for establishing multitiered monitoring systems capable of optimally assessing the current and long-term trends in the exposure to and the condition of ecosystems at multiple geographic and temporal scales.

3.3 Ecological Modeling and Process Research

Government Performance and Results Act SubObjective:
Develop models to understand, predict, and assess the exposure and response of ecosystems to multiple stressors at multiple scales

Process and modeling research develops the basic understanding and modeling technology to predict future landscapes, stressor patterns, ambient conditions, exposure profiles, habitat suitability, and probable receptor responses, as a function of risk management alternatives. Future models will consider multimedia, multipath sources, intermedia pollutant transfers, transport and transformations, microenvironments, and receptor activity patterns in the context of anticipated regional changes resulting from both natural and anthropogenic causes. In order to estimate the distribution of exposure to multiple stressors across vulnerable ecosystems, there is a need to understand and quantify the governing processes and develop models linking sources, transport, and transformations of pollutant stressors, along with physical stressor predictive models to estimate exposures at appropriate temporal and spatial scales. These models also must be linked to landscape models to characterize future environments and habitats.

In addition, ties to appropriate suites of biological response models are essential to the risk manager, because often the goal is to forecast the response of receptors to management actions.

For convenience and simplicity, current models used to predict the outcome of any individual management option are generally single media, involving only a single pollutant or stressor. Modeling must move past this piecemeal approach and represent the interactions that occur across scales, media, stressors, and multiple levels of biological organization (Figure 3-1). The complexity of the problems that EPA will face in the future will require models to predict beyond today's physical and chemical

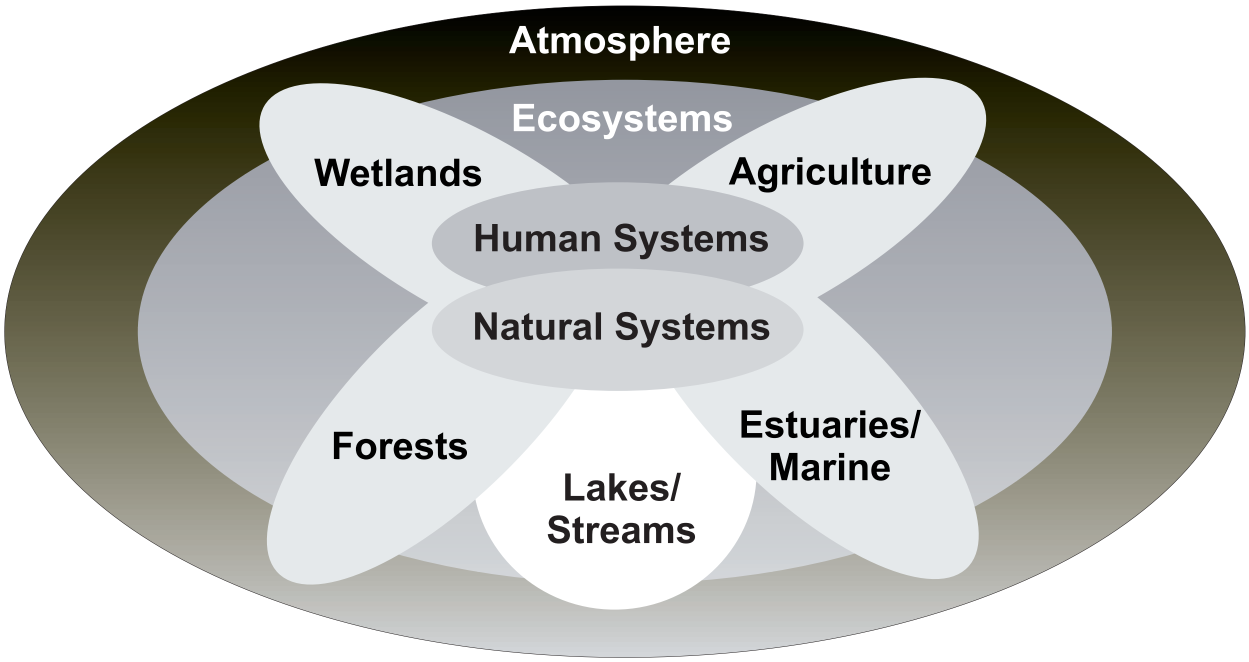

Figure 3-1. Conceptual diagram of integrated (multimedia, multistressor, multireceptor, multiscale) modeling.

conditions to new, never-before-measured conditions. Therefore, future models need to be based as closely as possible on first principles. They need to be sufficiently complex in their description of the underlying processes that they become virtual realities. By doing so, scientists can best advance the understanding of the whole of the environment and develop anticipatory and more flexible management strategies that avoid unwanted results. It is the vision for this area of research that future models will be interrogated as virtual realities in the same way engineering tables and interactive CD-ROM encyclopedias are used today.

To become the national leader in assessment, the next generation of models developed by ORD to predict exposure to and the effects of multiple stressors on ecosystems will be based on

- developing a "community"-accepted systems approach (a common framework) to support multimedia, multistressor modeling, both within and outside of ORD;
- developing state-of-the-science process algorithms and component computational models with flexible scaling to provide problem-solving methodologies that are applicable at multiple geographic and temporal scales and, therefore, are useful to environmental managers locally, regionally, and nationally, and for critical event, daily, seasonal, yearly, decadal, and longer timeframe assessments;
- systematic development and incorporation of state-of-the-science atmospheric, terrestrial, aquatic, and biotic compartment stressor and effects models necessary to predict real world conditions into the common framework; and

- improving the ability to interconnect, "cooperate", and exchange information in one system (e.g., the atmosphere), with another system (e.g., surface water ecosystems) with a different framework.

3.3.1 A Common Framework for Multimedia Exposure and Integrated Effects Modeling

Produce practical, reliable models for use by the environmental community on a full range of computing architectures from personal computers (PCs) to scalable parallel machines

3.3.1.1 Background

Historically, three distinct classes of exposure assessment problems at EPA independently have set the stage and defined the needs for an integrated multistressor, multimedia, multipathway stressor exposure modeling system: (1) regional air pollutant exposure assessments (e.g., acid deposition); (2) watershed pollutant, temperature, and sediment assessments (e.g., non-point source best management practice [BMP] strategies, total maximum daily loads [TMDLs], and water-quality-based permits); (3) groundwater system threat assessment (e.g., hazardous waste sites permits and pesticide management plans). The latter two problem classes involve the direct interaction of the land surface with the hydrologic cycle producing runoff of water and eroded soil (and related pollutants) to and through surface water ecosystems (fresh and estuarine) and the percolation of water and related pollutants to and through groundwater systems. Both are directly impacted by human activity (intensity and location) but also are naturally linked to atmospheric processes and forcing functions.

In addition, the development of regional atmospheric pollutant fate and exposure models launched ORD into the high-performance computing age. Although originally limited in multimedia scope, the early regional models had to address the atmospheric gas phase and the atmospheric cloud water phase, accommodate biogenic emissions from the terrestrial component, and account for removal by rain and by dry interaction with the land surface and vegetation.

In 1992, ORD actively joined the federal High Performance Computing and Communications Program (HPCC), thereby taking the first step toward development of an integrated exposure assessment framework. In the 6 years of involvement, the computational side of modeling in EPA has become state-of-the-art. In addition, environmental applications have become an important test bed for advanced computational approaches and visualization methods. For the future, collaboration with the community of federal HPCC researchers and academia, especially those engaged in environmental modeling, is important to the multimedia modeling research program from both the scientific and computational aspects. As part of its HPCC research, ORD developed a prototype, air-oriented environmental modeling framework, Models-3, that contains data and model management, data processing, parallel and cross-platform computing, and output visualization and analysis capabilities that generally are applicable to a variety of environmental assessment yields. A Community Multiscale Air Quality (CMAQ) model is being implemented within the Models-3 framework to specifically address air issues. Models-3 is an obvious starting point for a broader multistressor, multimedia model framework development effort.

The goal is to develop a comprehensive, integrated, flexible, scalable, and user-friendly multimedia, multistressor modeling system to predict the temporal and spatial distribution of chemicals (pollutants) in air, water, soil, and biota, for estimating the multiple pathway, cumulative exposures to selected ecological endpoints, and to predict the temporal and spatial distribution of ecological resources (i.e., populations/standing stocks for food and shelter, etc.) and habitat attributes (abiotic regimes/features needed for survival, reproduction, and recruitment) needed by ecological endpoints of interest. In other words, the goal is to provide the understanding and modeling tools necessary for holistic environmental risk assessment and risk management.

The specific objectives of this research area are to

- foster and establish a “community approach” to a multistressor, multimedia, multiscale environmental modeling system involving federal agencies, research institutes, and academia;
- foster active participation in the community development of scientific, technical, computational, and procedural guidance to facilitate the formulation and development of interoperable environmental modeling systems, interchangeable science process components, and network-accessible environmental data repositories;
- construct and maintain a community open architecture software system that enables (1) data access and management; (2) development, linkage, and execution of simulation modules at various spatial and temporal scales; and (3) visualization, analysis, and interpretation of model outputs across a full range of computing technologies from desktop PCs to scalable, parallel supercomputers across networks;
- formulate and develop state-of-the-science process and component modules that can serve as the fundamental building blocks for framework implementation;
- develop innovative techniques to resolve spatial and temporal mismatches encountered in multiscale, multimedia modeling, including tight integration of geospatial analysis and environmental process simulation;
- develop efficient computational approaches to meet increased demands of complex, multiscale, multimedia, multidimensional environmental models;
- develop dynamic, intelligent human-computer-network interfaces to assist users in access and synthesis of data, information, and knowledge related to environmental assessment issues, including model parameterization, uncertainty/sensitivity analysis, and innovative output techniques for visualization, multivariate analysis, and interpretation; and
- ensure appropriate framework links are available to ecological receptor effects databases; microenvironmental and effects databases; activity pattern databases; and socioeconomic, demographic, and climatic predictive forcing functions to assemble relevant, problem-solving methodologies using the framework.

3.3.1.2 Framework Development

Develop a prototype modeling framework for EPA; using the Mid-Atlantic region as a field laboratory

3.3.1.2.1 Rationale and Objectives

As indicated in the previous section, development of an integrated community framework for multistressor, multimedia, multipathway exposure (and risk) assessment modeling and, eventually, effects modeling as well is needed to take advantage of rapidly improving computer software and computational capabilities; to provide a standardized, less duplicative, more efficient assessment platform that is accessible for both upgrading and use by a wider range of environmental assessors and managers; and simply to cope with the expanding scope of exposure and risk assessment needs being imposed on EPA by congress and the nature of emerging environmental management and remediation problems.

The approach will be to exploit and expand the software features of the Models-3 prototype into the general framework and to incorporate developmental and existing media computational models, themselves to be systematically upgraded with respect to their process descriptions (i.e., transport, transformation, sources, and sinks algorithms), in a phased manner based on application priorities and resources availability.

The overarching longer term objectives for the framework development were provided in the previous section. Shorter term objectives include

(1) plan and conduct a comprehensive, multimedia, multistressor ecosystem exposure assessment case study on a selected subregion of the Mid-Atlantic Integrated Assessment Area (MAIA) to provide a rapid prototype focus for framework development;

(2) write draft coding guidelines for community review and acceptance, with emphasis on code and data set integration;
(3) obtain general use and distribution licensing for software for framework development;
(4) develop a data dictionary for those data shared by the media-specific modules anticipated for use in the ecosystem exposure assessment case study;
(5) evaluate and revise the Multiple Resource Land Cover (MRLC) database for use in the ecosystem exposure assessment case study;
(6) phase in, as rapidly as possible, the integration into the framework of media/component modules anticipated for use in the ecosystem exposure assessment case study (i.e., HSPF, PRZM, EXAMS, BASS/FGETS, and a habitat suitability model [terrestrial and aquatic]);
(7) phase in a second round of modules, focusing on WMS-GMS, WASP, Estuary Model, a to-be-selected lake/reservoir model, SED2/3, QUAL2E, pNEMS, and $PM_{2.5}$/Ozone;
(8) start simple linkages with to-be-selected predictive meteorological and land use change models for the ecosystem exposure assessment case study (incorporate socioeconomic drivers to the extent possible); and
(9) address spatial and temporal mismatches for those modules to be used in the ecosystem exposure assessment case study.

3.3.1.2.2 Specific Research Foci

The following areas will be foci for the further development of the framework.

Atmospheric-Terrestrial Interaction

Water exchange is the principal basis of pollutant transfers and subsequent transport. Gases and aerosols can be stored and freely exchanged between the atmosphere and the biosphere. Modeling these reservoirs and fluxes requires an intricate understanding of many different processes, including bacteria, plant physiology, micrometeorology, and biochemistry. Biogenic processes, many of which are perturbed by anthropogenic activity, can cause emissions of VOCs from vegetation; nitric oxide, nitrous oxide, carbon dioxide (CO_2), and carbon monoxide (CO) from bacteria in soil; methane from wetlands; and sulfurous compounds from water bodies. Biological processes also can transform, reroute, and reschedule the exposure pathways of anthropogenic compounds such as dioxin, mercury, and nutrients. In addition, plant matter can store many pollutants, which then can be either ingested by animals or rereleased into the environment. Because these processes involve several compartments and media (water, air, soil, vegetation, bacteria, and other living organisms), requiring an understanding of complex processes and interactions, developing net flux and other transfer linkages between compartmental models will continue to be a long-term research challenge for the framework development. The initial emphasis will be on those compartment modules needed for the multimedia, multistressor ecosystem exposure assessment case study within MAIA. Flux rate, transformation, sorption, etc., process algorithms will be developed/upgraded for the needed component modules, based on the research described in the following.

Spatial Scales

The nesting feature of the Models-3 prototype computational framework already can handle a wide variety of spatial scales; however, the environmental process modules and databases have a much more limited range of applicable spatial scales. Resolving the incompatibilities in the spatial scales of different processes is a significant research area requiring additional process understanding for each media/compartment. Sub-grid scale features must be handled within current science formulations; however, bases for process formulations typically are based on site measurement studies that may not be representative of the full texture and complexity of the grid scale modeled. For example, dry deposition formulations based on single land use type in a grid cannot represent the deposition resulting from heterogeneity resulting from its actual multiple land use. Transport processes (such as those involved in convective turbulence, clouds, etc.) are known to be scale-specific, but their formulations may be inadequate for the modeling of wide scale ranges. Linkages between atmospheric processes and between atmospheric and land/water surfaces may be crucial for accurate simulations of pollutant concentration and deposition fields; however, process formulations often are oversimplified, and the resulting linkages are poorly or inadequately modeled. Most of these spatial scale issues must be handled within the various compartment transport modules (e.g., air, lakes, estuaries, watersheds, etc). The first framework scalar issue is likely to be the ecosystem exposure assessment case study within MAIA, particularly if the selected subregion problem involves nitrogen and estuaries.

Temporal Scales

Time scales for modeling ecosystems extend over a vast range, from seconds and minutes for chemical processes, to minutes to hours to daily to seasonal for atmospheric and hydrologic transport and deposition processes, to decadal and beyond for ecosystem response to bioaccumulation and climate and land use change. The linkages between the media components, whose processes often operate on vastly different time scales, must be recognized, and suitable operational techniques (e.g., aggregation, statistical, etc.) developed and implemented in the framework to deal with those mismatches. The degree of direct process coupling (e.g., wind and wave/currents, toxic exchanges between air and water, etc.), versus linking of module outputs and inputs for the different media, also needs to be examined and optimized. The first practical attempts to deal with this problem will be the ecosystem exposure assessment case study within MAIA (i.e., for the compartment modules to be integrated within the framework for that study and the human health case study). A particularly stringent test will involve the WMS-GMS integration process for ecosystem modeling.

Grid Structure for Coupling Processes/Models

The underlying computational grid structure used to simulate physical, chemical, and biological processes in two or more dimensions is dependent on the nature of the process, the underlying assumptions of the scientific theory, and the computational approach. Therefore, underlying grid structures may vary with each process, both within and across media/compartments. To facilitate the transition from one-dimensional models toward higher dimensional models with spatial and temporal coupling at either the process or module level, there must be a tight coupling of science process models with geospatial analysis techniques to enable interprocess exchange of data.

Another major difficulty with many multimedia models is the labor-intensive nature of the input data preparation because of the type, complexity, and spatial variability of the required input data, especially where unstructured, irregular grids are involved (e.g., in estuarine and large lake hydrologic and pollutant transport module boundary conditions). Embedded spatial analysis capabilities can reduce the burden involved with preparing spatially and temporally varying input data for models. For the framework development process, this will become a very acute issue as river, lake, and estuary compartment modules are integrated therein.

Databases

The initial focus on databases relative to the framework will be to identify those needed for the ecosystems exposure assessment case study. Once identified, a data dictionary must be developed, and code guidelines established and implemented to facilitate their access and use. There are some obvious candidates (e.g., the MRLC, endangered aquatic and terrestrial species, AQUIRE, Phytotox, Terratox, Soils, meteorological, U.S. Geological Survey gauging station, REACH, etc). Another critical linkage required is to pollutant transport and transformation parameter databases and computerized estimation systems, such as SPARC for organics and MINTEQ for metals. Development of these estimation techniques is discussed under the transport and transformation processes research sections of this strategy.

3.3.1.3 Integrating Exposure and Effects Modeling

Provide state-of-the-science, framework-formatted, single and multimedia, stressor exposure assessment models/modules linkable/linked to eco-effects models and databases for risk characterization across trophic and geographical scales

3.3.1.3.1 Rationale and Objectives

It is important to ensure that the developmental exposure assessment framework will possess the appropriate linkages to ecological effects databases and models for all levels of biological organization. This includes habitat suitability in the broadest sense for terrestrial, surface water-sediment, and soil-subsurface environmental compartments. Another concern is the activity-ranging patterns and predator-prey interrelationships needed for food-web exposure and impact analysis and the habitat suitability assessment for key ecological species and populations.

Some of these connections will be more definitively identified and implemented at the media component level in support of selected "community-based ecoprotection" projects (e.g., Everglades Restoration, MAIA, Pacific Northwest, etc.). More detailed connectivity identification will be a feature of the integrated, multistressor, multimedia ecosystem exposure assessment case study within MAIA. Once the case study has been completed, and expanded framework development and implementation is initiated (e.g., in MAIA follow-ups or in new regional studies), those effects models and databases found to be most useful for general "risk characterization-assessment" will be linked to the exposure framework.

Specifically, the objectives of this research are to

- develop state-of-the-science, tailored, linked, compartment and multimedia exposure-risk assessment frameworks in support of selected community-based ecoprotection efforts and case studies and assist in their field testing and application;
- identify and establish appropriate links for general effects databases and models, such that the developmental framework can address both pollutant and nonpollutant stressors, including habitat alteration/loss, climate change, etc;
- ensure socioeconomic drivers and climate change are accounted for relative to predicted land use change and habitat alteration, both terrestrial and aquatic, within the framework;
- focus special attention on the development of and linkage to a spatially distributed watershed response model as a major required new component model for multimedia, multistressor eco-risk characterization, assessment, and restoration design and as a framework element; and
- test these developmental compartment risk assessment modules and especially the prototype multimedia, multichemical, multipathway ecosystem risk assessment module for restoration design, watershed diagnosis, and regional ecosystem assessment and rule-making, via application in South Florida-Everglades and the MAIA ecosystem exposure assessment case study and subsequent regional assessments.

3.3.1.3.2 Specific Research Foci

The main foci are the integrated exposure-effects compartment models needed for the MAIA assessments and their development and implementation. Habitat change and suitability predictive modeling is another focus that will be pursued in the context of demographic development, socioeconomic, and climate change forcing functions. The long-range focus involves the systematic and phased integration of these linked, compartmental models and databases into the general framework.

Multiscale Modeling

Answers and knowledge requirements about stressor exposures and habitat alteration, and the resulting ecological responses, are required for different scales—temporal, spatial, and ecological organizational. A great range of scales must be considered in the context of local and regional decision making. A region such as the Mid-Atlantic is at mid-scale, encompassing scales of local concern and thereby providing a context within which local-scale problems can be considered. At the other end of the range of scales, global changes (both climatic and other human-induced changes) affects regional and larger scale processes. The uncertainty in climate change and development-demographic projections makes predictions of regional changes more difficult. Problems often occur in attempting to apply knowledge gained from studies at a given scale to a very different scale, such as the routine application of a process description developed in a laboratory setting to a field-scale projection. The major difficulty to be overcome is whether any description used is an adequate model of the process as it functions in the environment, where influencing factors cannot be controlled. ORD will bring many such scale problems to the fore and anticipates greater research effort to be directed to the application of tools developed for local-scale, or even scale-free, generic applications to subregional and regional ecosystem assessments.

Local Scale—Many problems that occur at the local scale are related to toxic and hazardous wastes. Modeling research in this area focuses on metals fate processes (speciation and sorption); anaerobic transformation processes; advanced multipollutant, multimedia, multipathway source-to-dose exposure-risk model development (air, landfill, farmland, and waste pile to surface and groundwaters); and application/testing of developmental exposure modeling techniques. Testing applications on other selected problems, such as screening for endocrine-disrupting compounds, will be required to test and verify developed technology.

Regional Scale—Environmental problems at regional scales are the emerging issues for the next century. Contaminants such as nitrogen, mercury, and many endocrine disruptors are subject to cross-media, long-range transport, and the ecosystem protection research program must work in concert both with specific EPA program office media (Water, Air, Pesticides/Toxics, and Waste) and with multimedia research programs to address these issues. State and regional planners need integrated, accessible multimedia assessment tools to develop control strategies.

Airshed models, particularly for ozone, sulfur, and nitrogen, are beginning to be used at the regional scale; and EPA has an aggressive program under the HPCC initiative to develop regulatory tools and put them in the hands of regulators. However, the widespread deployment of these tools remains in its infancy because only crude integration of the multimedia exposure modeling system components currently exists for these pollutants. Continued framework and compartment model development, as described above, will alleviate this problem.

Watershed assessment, in the context of regional scale analyses, such as currently implemented in the Chesapeake Bay Watershed model, must encompass a wide variety of terrestrial systems—forested (both managed and unmanaged), agricultural, and urban systems—and aquatic systems with point and non-point sources of pollutants and contaminated sediments. At the watershed scale, stressors as varied as temperature, dissolved oxygen, suspended sediments, nutrients, ammonia, toxic organics, and metals are all potential environmental threats. Other major challenges exist in understanding the biogeochemical cycling of substances in complex systems, such as mercury in the Everglades and PCBs in the Great Lakes. A major challenge in these systems is the development of ecological indicators of stress and integrating watershed assessment tools with those for airshed and coastal systems.

Coastal systems are subject to stress from contaminated sediments, direct air deposition, and non-point source pollutants, particularly nitrogen, as well as from riverine inputs and loss of habitat, and present their own special challenges for assessment. Again, linkage with airshed and watershed assessment tools is in its infancy, but the impact of long-range transport of pollutants like nitrogen and mercury must be at the top of ORD's research agenda.

Global Change—Sensitivity of organisms and natural communities to environmental stresses is a property of climate. For example, Pacific Northwest, high plains, desert Southwest, and Mid-Atlantic communities differ in ways that are mostly established by their respective climates, and they are likely to be sensitive to different stressors and to given stressors at different levels. Moreover, the vulnerability of natural communities to many stressors can be expected to increase with climatic change because climatic stress will reduce the physiological space available to respond to other stresses. Global change is anticipated over perhaps a 10- to 100-year time scale and must be taken into account in any holistic or cumulative risk assessment. Global change research consists of two components: (1) a modeling component and (2) a processes component. The processes component focuses on specific issues of importance related to global change, either contributing to, in response to, or in the context of global change and territorial feedback effects. In general, process research will bring out specific new issues or elucidate process mechanisms that will improve the predictive capability of the precipitation estimates of global change models. Process research can apply generally (e.g., reactions in atmospheric chemistry) or can be focused on processes of importance to a particular region (e.g., nitrous oxide and methane production in boreal forests). The modeling component has focused on the synthesis of a fully coupled Earth Systems Model (ESM), with in-house research primarily dealing with a soils biogeochemistry component. This model will predict future atmospheric greenhouse gas concentrations and the accompanying climatic changes, as well as incorporate some of the natural biospheric feedbacks, and, consequently, could predict somewhat different future climates than are predicted by existing general circulation models. A recent focus has been the prediction of future regional climates, using a mesoscale model embedded in the global scale model to support regional scale assessments of ecological sensitivities.

The integrated focus is on determining how regional ecosystems are vulnerable to socioeconomics/demographics, land use change, climate change, habitat alteration, modifications to ecosystem structure and diversity, and other large-scale environmental perturbations such as mercury, acid deposition, pesticides, eutrophication, etc. The primary focus will be on methodology application to the Mid-Atlantic and Southeastern United States. Results of this work will permit advances in regional- and state-level vulnerability assessments and national-level integrated assessments. This will enhance EPA's ability to develop realistic bounds on the nature and magnitude of the vulnerabilities identified and to assess the costs of mitigation and adaptation strategies—particularly where habitat, chemical, climate, and management stressors interact. Research includes

(1) laboratory and field studies to understand and characterize how ecosystem/biospheric components change as a consequence of human-caused and naturally occurring long-term environmental perturbations; and
(2) modeling land use and climate change to predict consequences of additional long-term perturbation and mitigation efforts. In addition to the global change research being conducted, additional airshed and watershed modeling efforts will evaluate fate and possible exposure levels of toxic chemicals and nutrients for regional vulnerability assessments.

Model Coupling

Model coupling at all scales and for all ecosystem endpoints of concern will be performed through the general multimedia modeling framework described previously. In the framework developmental-transition period, model coupling, which links related ecosystem impact assessment modules, will be at the watershed and site scale. Prototype component/media ecosystem assessment models already exist at watershed, large lake, estuary, and site scales. These will be updated with respect to stressor exposure algorithms, effects, and activity database linkages and impact assessment modules during the transition period (2 to 5 years), and then incorporated into the general framework in a planned, phased approach.

3.3.1.4 Implementation

This research and development is conducted primarily in-house by EPA and National Oceanic and Atmospheric Administration (NOAA) researchers, except for framework software efforts conducted via contract and ESM by interagency and cooperative agreements. Future integration of large lakes STAR grant modules into the framework will be required. Although component module upgrades and their integration into the framework largely will be accomplished by EPA and NOAA staff, some contract support and interagency agreement activity also may be required.

3.3.1.5 Government Performance and Results Act Milestones

- **By 1999**, provide updated methodologies and models for regional ecological exposure assessment.

- **By 2000**, complete development of an improved version of HWIR multimedia, multipathway modeling methodology for assessing (ecological) exposures associated with listed waste constituents.
- **By 2001**, complete development of ecological models for regional vulnerability assessment; publication of significant research findings from mesocosm experiments, field studies, and modeling studies on reducing global and transboundary risks.
- **By 2004**, complete exposure assessment of ecosystem vulnerability to pesticide contaminants over regional scales; recommend, evaluate, and adopt a modeling architecture for integrating atmospheric, terrestrial, and aquatic exposure and effects models.
- **By 2003**, complete development of multimedia, multipathway exposure and fate models for integrating human and ecosystem exposure and risk over time and space.
- **By 2004**, develop and demonstrate a multiple pathway, multiple chemical model that integrates human health and ecological cumulative exposure and risk assessments.
- **By 2005**, develop advanced measurement, computing, modeling, and data management technologies and integrate them into an effective system for real-time delivery of multimedia, multipollutant environmental status and risk.
- **By 2008**, deliver an integrated exposure and effects modeling system to be tested and evaluated.

3.3.2 Improving Atmospheric Exposure Modeling

Develop a state-of-the-art air quality modeling system capable of handling multipollutant issues and multimedia interactions and a second such system capable of handling multipollutant issues and multimedia interactions

3.3.2.1 Background

Consistent with the development of a common modeling framework is the need to improve the exposure and effects models that will go into the framework. The next sections will present the high-priority research areas in atmospheric, terrestrial, and aquatic exposure modeling and effects modeling.

Atmospheric pollutant fate and transport research is focused on the Models-3, third-generation modeling system. This platform provides an integrating mechanism for this research across EPA and the atmospheric modeling community at large.

The initial version of Models-3 focuses on urban- to regional-scale air quality simulation of ground-level ozone, acid deposition, visibility, and fine particulate matter. The Models-3 framework provides an interface between the user and operational models, between the scientist and models under development, and between the hardware and model software. This allows the user to perform a wide range of environmental tasks, from regulatory and policy analysis to understanding the interactions of atmospheric chemistry and physics, while rapidly adapting to new technology.

Atmospheric processes research focuses on the formation, chemistry, transport, and behavior of gases and aerosols in the atmosphere, plus fundamental research in source apportionment, aerosol physics, and particulate matter chemistry and fate. Pollutants of interest include ozone, nitrogen oxides (NO_x), NO_y, and VOC species and urban hazardous air pollutants.

The objectives of this research are to

- develop a state-of-the-art, “one-atmosphere”, air quality modeling system capable of handling multipollutant issues (e.g., oxidants, acid deposition, visibility, fine particulate matter);
- provide advanced air quality modeling capabilities with the flexibility to operate at a spectrum of spatial scales, including regional, urban, and point source (e.g., via the continued development of the CMAQ model);
- provide a standard interface that facilitates interchange of science modules;
- serve as a basis for research into advanced science issues (e.g., visibility, air toxics, acid aerosols), multiscale interactions (e.g., multilevel nesting, adaptive grids), mixed- and cross-media issues, and physical and chemical processes;

- serve as a basis for diagnostic evaluation and continuing modeling system development;
- incorporate an advanced approach to sensitivity and uncertainty analysis;
- more closely couple meteorological models with chemistry-transport models (e.g., a quasi-coupling of MM-5 with CMAQ);
- take advantage of the enhanced computational capabilities provided by high-performance computing and communications (HPCC) architectures; and
- offer sufficient extensibility to address and fulfill EPA's anticipated air quality research modeling needs.

3.3.2.2 Emissions Process Research

Characterize emissions factors for anthropogenic and natural sources to improve atmospheric model forecasts

3.3.2.2.1 Rationale and Objectives

Specification of the emissions source terms is a critically important factor in accurate air/water quality modeling applications. Generally, the emissions fluxes contain the most inherent errors and uncertainties of all of the required input parameters in air/water quality simulation. Yet, it is these fluxes that are the independent variables that are modulated in modeling exercises to seek the optimum emissions control strategies for the improvement of environmental quality. Thus, ORD maintains a strong research focus on the understanding of source emissions processes and improvement in the estimation of emissions fluxes.

Emissions may be categorized as anthropogenic (man-made) or biogenic (natural). Some emissions sources may be combinations of these categories, such as nitrogen emissions from soil fertilization or ammonia from swine farming. Generally, if the emission source is considered to be potentially controllable, it is categorized as anthropogenic; if it is perceived as not being appropriate or amenable for control measures, it is treated as a natural source.

For each process that produces an emission, an emission factor must be determined. This "emission factor" is a measure of the gross emissions per unit of work performed by the process (e.g., grams of emissions per mile driven [mobile sources] or grams of emissions per ton of fuel consumed [utility boilers]). Each emission also produces a characteristic "source profile", or list of specific chemical compounds emitted per unit mass of gross emissions. The final factor in flux estimation is the "activity level", or the amount of time that an emission process is active, at what level of intensity for any specific location. Therefore, the objectives of emissions process research within ORD are

- to characterize and refine the emissions factors for significant anthropogenic and biogenic sources that contribute to air/multimedia pollution problems;
- to determine the chemically speciated source profiles of significant emission source processes;
- to characterize levels of anthropogenic and biogenic emissions activity as a function of emissions process, location, and time (by hour, day, month, or season, as appropriate); and
- to build, refine, and maintain models and databases of emission factors, source profiles, and activity levels applicable to North American locations that may be used in air/multimedia quality modeling applications.

3.3.2.2.2 Specific Research Foci

Mobile Source Research

Emissions from mobile sources (i.e., automobiles, buses, trucks, boats, etc.) constitute a very large fraction of the emissions of air pollutants or precursors of air pollutants of concern, including CO, NO_x, VOCs, fine particles, and various toxic compounds. VOCs and NO_x are precursors to ozone formation, a major pollutant of terrestrial ecosystems. These emissions sources have received considerable study over the last 30 years. However, most of the studies were performed in controlled environments such as smog chambers and dynamometers. More recent studies conducted in "real-world" settings, such as roadway tunnels, have shown that earlier emissions estimates were generally biased low. Many factors contribute to this bias, including vehicle aging and performance degradation, acceleration/deceleration in on-road operations, and power enrichment on steep grades. Current and future research must be focused on the emissions from vehicles in real-world operation and reconcile these findings with the controlled environment experiments to produce more realistic estimates of on-road mobile source emissions fluxes.

Recent estimates of emissions from on-road, heavy-duty diesel vehicles and off-road recreational and marine engines have shown that these mobile source categories may become more dominant as their activity levels increase and their share of the mobile source emissions increases because of better emissions controls on the on-road, gasoline-powered fleet. Emissions of NO_x, VOCs, and fine particles, in particular, are issues from these source categories. Considerably more research is needed to estimate real-world levels of emissions from these sources. Interest continues in exploring further emissions reductions from gasoline powered vehicles through use of alternative and reformulated fuels. Some such fuels show promise in reducing toxics and ozone-precursor emissions, and further research is needed to quantify the potential benefits of using a variety of oxygenated and lower-volatility fuels, as well as clean-burning alternatives such as compressed natural gas.

Biogenic and Other Natural Emissions Research

Emissions of reactive VOCs from trees and other vegetation are a significant source of ozone precursors and organic particulate air mass in many portions of North America. These emissions have only recently (within the last 10 years) been characterized, and there remain large uncertainties in emission factors from many tree and vegetative species and in the areal coverage of particular emitting species. Environmental modulation of the emissions fluxes is also an area where more research is needed. Biogenic emissions from trees and vegetation are affected by temperature and solar radiation. Heat, moisture, and pollution stress may greatly change the emission factors from particular species.

Atmospheric chemistry models (regional and global) calculate the emissions of volatile organics (oxidant precursors) from vegetation. A large degree of uncertainty accompanies these estimates because of errors incurred through accurately scaling spatially and temporally limited data to landscape (grid) scale, as well as accurately predicting emission-controlling variables such as temperature and radiation gradients within vegetative canopies. Research will focus on wider range measurement of biogenic VOCs over both hardwood and pine forests and examining other poorly understood emission controlling variables, such as water availability/stomatal control. Additionally, plans are being developed to study emissions from forest thinning. Ultimately, these measures will be used to improve the algorithms used in the Regional Oxidant Model (ROM).

Other natural air sources of NO_x are lightning, (fertilized) soil, and photo-oxidation of dissolved organic matter. Estimates of emissions magnitudes here are quite uncertain and highly variable. Research is needed to quantify better the magnitudes and variability of these emissions sources. NO_x emitted from soils has a high potential for rapid ozone formation in the vicinity of other sources of VOC emissions. Mercury and ammonia emissions have received much attention recently. Estimates of both are very crude at this point, and more basic data are needed to improve the flux determinations. Mercury (a toxic contaminant) emissions are highly dispersed and are, in part, natural. Ammonia (important for nitrogen deposition and fine particle formation) emissions are attributed mostly to agricultural activity, although there is a significant, but undefined, purely natural component. Estimation of pesticide (toxic) emissions poses great challenges as they vary with temperature, application mode, plant cover, and soil, as well as the physical and chemical composition of the pesticide. Suspension and resuspension of wind-blown dust is important to the estimation of particulate and visibility pollution. Geogenic and volcanic activity and biomass burning are also responsible for much of the global natural emissions of many substances, although these terms generally are characterized by background concentration levels and are not used as specific source terms for regional and urban modeling applications. Nonetheless, better estimations are required for the background characterization.

Stationary and Area Source Research

Emissions from large point sources (such as utility boilers used in power generation) generally are characterized, especially for sulfur and nitrogen emissions. Variations in temporal operating patterns can still be difficult to characterize, although,with the advent of continuous emissions monitoring (CEM) data at these facilities, this may be less of a problem in the future. Emissions of mercury and other heavy metals from large point sources are less well characterized,and more work must be done to improve these estimates.

Other widespread area source emissions, such as from solvent use, surface and architectural coatings, pesticide applications, etc., are difficult to estimate because of their intermittent and widespread use. Reliance on surrogate indicators, including population, housing, and farming data is necessary. Research is needed for evaluation of regional estimates of these emissions fluxes from the use of surrogate indicators.

3.3.2.3 Wet/Dry Deposition Research

Understand wet and dry deposition processes, develop and improve deposition models, evaluate models with deposition data, and describe the spatial and temporal extent and trends in deposition.

3.3.2.3.1 Rationale and Objectives

Deposition is the main pathway for all pollutants from the atmosphere to the biosphere (land and water) and the geosphere. All pollutants moving from the atmosphere to plant communities, animals, soils, water, etc., do so by this route. Thus, to understand exposure of ecosystems to airborne pollutants, an understanding of deposition processes is essential. Deposition is dependent on pollutant, plant species, plant physiology, surface properties, and atmospheric transport and diffusion. To understand and model deposition, all the above processes must be understood. From the atmospheric perspective, deposition is also a major loss pathway for pollutants. Atmospheric models must accurately account for deposition in order to model chemical transport, transformation, diffusion, and fate correctly.

The objective of this research is to understand wet and dry deposition processes, develop and improve deposition models, evaluate models with deposition data, and describe the spatial and temporal extent and trends in deposition.

3.3.2.3.2 Specific Research Foci

The objectives of this research will be to

- measure fluxes of sulfur dioxide (SO_2), ozone, and nitric acid (HNO_3) to forests and to evaluate existing point and regional deposition models;
- measure fluxes of SO_2, ozone, and HNO_3 to surface waters, fresh and estuarine, and to evaluate existing point and regional deposition models;
- develop methods to measure net intermedia fluxes of NO, nitrogen dioxide (NO_2), amonnia (NH_3), mercury, toxics, pesticides, and fine particles and develop and evaluate intermedia transfer models;
- measure fluxes of SO_2, ozone, and HNO_3 over land and surface waters during the winter and evaluate existing intermedia transfer models;
- develop techniques to measure fluxes over complex terrain and apply and evaluate intermedia transfer models;
- conduct analyses of air pollutant (i.e., ozone, sulfur, and nitrogen) dry and wet concentration, deposition velocity, and dry, wet, and total flux (These analyses will address temporal behavior [e.g., annual and seasonal], spatial distribution, climatological/meteorological variables, transformation processes [i.e., atmospheric chemistry], and coupling with emissions.);
- develop third-generation deposition models (These are models that take into account the cell level chemical reactions that occur in the leaf.);

- develop a better understanding of the turbulent processes that control some deposition processes and incorporate them into operational deposition models (This may include LES [Large Eddy Simulation] modeling.);
- through experiments and modeling, develop an understanding of nocturnal processes, both at the plant and atmospheric level, that control deposition at night; and
- develop and apply methods to measure fluxes of aerosols and develop, refine, and evaluate existing models.

3.3.2.4 Community Multiscale Air Quality Modeling

Deveolop a "one-atmosphere" model, integrating chemical and meteorologic processes

3.3.2.4.1 Rationale and Objectives

EPA is developing an advanced air quality modeling system, Models-3/CMAQ, as a state-of-science assessment tool for scientific analyses of air pollutants, their loadings and distributions, as well as to provide a tool for determining the efficacy of various control scenarios. The chemical composition of air (and in the case of airborne particles, their size distribution) is controlled by numerous atmospheric processes that operate over large ranges of temporal and spatial scales. Models-3/CMAQ is a flexible and general modeling system designed to support computational scalability for multipollutant and multiscale air quality simulation, while taking advantage of the enhanced computational capabilities provided by HPCC architectures. CMAQ is an emissions-based, Eulerian framework, air quality modeling system that integrates state-of-the-science physical and chemical process algorithms with efficient numerical solvers and data linkages. The inclusion of particles in air quality simulation models will allow the capability for modeling heterogeneous processes. The various processes inclusive of transport and deposition, as well as the chemistry, are therefore much more adequately and credibly simulated. Models-3/CMAQ will provide a basis for understanding the complex temporal and spatial distribution of air pollution on scales ranging from airshed/watershed to regional (subcontinental) scales. In addition to its use as an implementation tool for simulating ground-level ozone, acid deposition, visibility, and fine particles, CMAQ is designed to be implemented for assessments of transport and deposition of heavy metals (including mercury), toxic semivolatile organic compounds (SVOCs), and nitrogen and other airborne nutrients that impact sensitive receptor ecosystems.

3.3.2.4.2 Specific Research Foci

Develop SVOC Capability in Models-3/CMAQ with Particulate Matter

The portions of the total atmospheric concentration of SVOCs that exist in gas and particulate forms are defined in terms of gas/particle (G/P) partition functions. Given G/P functions, the SVOC fields can be mapped to the particulate fields predicted by Models-3/CMAQ. These G/P partition functions are typically functions of air temperature and the overall aerosol loading of the air. The results of ambient monitoring investigations previously have suggested that the surface area concentration of the total aerosol loading is a primary determining factor for the G/P partitioning of most SVOCs. Consideration also must be given to the possibility that particle absorption may be more important than particle adsorption in drawing SVOCs into the aerosol form, and that the volume concentration of total aerosol loading may be a more accurate indicator of G/P partitioning, at least for some SVOCs. Studies to incorporate both the absorptive and adsorptive theories in modeling the G/P partition functions will need to be conducted. CMAQ model simulations will provide the particle mass loading and particle size distribution information required to estimate G/P partitioning of SVOCs with a capability for predictions up to three nested domains with grid size resolution of 36-, 12- and 4-km.

Toxic equivalency (TEQ) is an important issue that relates to PCDDs, PCDFs, PCBs, and other air toxics that exist in a variety of congeners. Previous assessments of PCDD and PCDF emissions and exposure patterns were based on an integration of toxicity from all congeners in terms of an equivalent dose of 2,3,7,8-tetrachlorinated dibenzo-*p*-dioxin, the most toxic of all PCDD and PCDF congeners. It is known that the tetrachlorinated congeners tend to have a higher vapor pressure than the more chlorinated ones and, thus, usually exist in gaseous form. These tetrachlorinated congeners are also more toxic. The less toxic and higher chlorinated congeners are found usually in particulate form and can wet and dry deposit to the ground more easily. Thus, there is a relationship between toxicity and atmospheric behavior for PCDDs, PCDFs, and PCBs, although an indirect one. Each congener must be simulated separately in atmospheric modeling to obtain an accurate assessment of the exposure to total toxicity at any particular location. Congener-specific emission inventories of industrial sources of PCDDs, PCDFs, etc., are needed. Similar inventories of nonindustrial sources (e.g., forest fires) also are needed for congener-specific atmospheric modeling to assess their concentration and wet and dry deposition patterns. Once these patterns are estimated, TEQ analysis can be performed on the modeling results to allow comparison to previous estimates of air toxic exposure.

Modeling Mercury and Other Heavy Metal Deposition

Modeling transport and deposition of inorganic particulate metals such as arsenic, cadmium, and lead, and atmospheric mercury in three forms—(1) elemental gas (HgO), (2) divalent gas (Hg_2^+), and (3) particle-bound—is important to assessing potential adverse impacts on sensitive ecosystems. These compounds are known to bioaccumulate, thus impacting adversely the biota in ecosystems. Atmospheric mercury is known to exist in both gaseous and particulate forms, but its G/P partitioning is not thought to be a function of vapor pressure, as is the case for typical SVOCs. It appears that particulate mercury is formed at or near the emission source by the adsorption of ionic mercury compounds to carbon soot and other aerosol materials. Once attached to these aerosol particles, this mercury is affected by coagulation with other particles. Therefore, the total mass loading and particle size distribution of all aerosol material in the air must be known to simulate the behavior of particulate mercury, just as with SVOCs. Furthermore, mercury, especially the elemental form, is known to be a global pollutant. Its current modeling using Lagrangian approaches is severely limited.

Develop Aggregation Schemes for Application Studies

A major limitation for implementation of CMAQ is the modeling of seasonal and annual average concentration fields from CMAQ episodes, consisting of up to 5 days of simulation time. To circumvent this problem, aggregation methods, initially developed for acid-deposition applications, have to be tested and improved for use in modeling deposition of toxics, heavy metals, and nutrients. The aggregation methodology is based on the premise that at any given location, ambient air concentrations are governed by a finite number of different, though recurring, meteorological regimes. The aggregation procedure estimates mean annual concentrations using a predetermined set of model simulations selected from the meteorological strata. Calculation of the mean annual concentrations makes use of weighting/scaling factors that are based on the frequency of occurrence and the expected concentration for each of the strata associated with the events selected for aggregation. Efforts will be needed to investigate the adequacy of the current capability developed for the acid deposition studies.

Perform Model Evaluation

Model evaluation is an essential component of science-based air pollution model development. State-of-the-science models are, by their nature, not merely statistical relationships that can be tuned, but are composed of numerous, first-principle parametric representations of atmospheric and landscape processes based on limited but diverse studies. Model quality objectives must be formulated, and a program of model evaluation must be established to assure high quality and utility of the modeled results.

3.3.2.5 Implementation

This research and development is conducted primarily by EPA and NOAA in-house researchers, especially in the areas of model component development and evaluation. Contract support is required for emissions data gathering and for field measurements of deposition fluxes. Other agency collaborative research and results of STAR grants also will be integrated into improving atmospheric exposure modeling.

3.3.2.6 Government Performance and Results Act Milestones

- **By 1999**, Phase I of diagnostic evaluation of Models-3/CMAQ is to be completed against comprehensive field study data sets.
- **By 2000**, Phase II of diagnostic evaluation of Model-3/CMAQ is to be completed against comprehensive field study data sets. Mercury modeling capability is incorporated into Models-3/CMAQ.
- **By 2001**, more advanced chemical kinetic mechanisms and meteorological process algorithms are to be incorporated and tested in the Models-3/CMAQ system. Phase I evaluation of mercury modeling, using Models-3/CMAQ framework, is to be completed, and an integrated, evaluated air chemistry, fate, and transport model for coupling to existing terrestrial and aquatic models is to be delivered.
- **By 2002**, methods for assessing the errors and uncertainties in air quality predictions from the Models-3/CMAQ system are to be incorporated and tested, and SVOC modeling capability is to be incorporated into Models-3/CMAQ.
- **By 2003**, model evaluation exercises are to be conducted with a newly revised version of Models-3/CMAQ; the evaluation focuses on urban- and local-scale pollution problems and the larger scale influences on those problems; preliminary evaluation of Models-3/CMAQ for SVOCs is to take place.

3.3.3 Improving Aquatic and Terrestrial Exposure Models

Understand, quantify, and model key transport and transformation processes for radiatively important trace gases (RITGs), nutrients, industrial chemicals, pesticides, and metals, and incorporate these as source-sink terms into state-of-the-art terrestrial and aquatic assessment models

3.3.3.1 Background

The uncertainties associated with predicting terrestrial and aquatic ecosystem exposures and responses to pollutant stressors are heightened greatly by ORD's frequent inability to incorporate quantitative descriptions of these stressors' cycling, speciation, intermedia transfers, sorption, and transformation/degradation. These processes determine not only the ambient concentrations of pollutants and their transformation products available for direct and indirect ecosystem receptor exposure, but also the pathogenic, chemical, toxicity, oxidation-reduction potential, and sediment and nutrient status factors relative to general habitat suitability and overall risk characterization.

Based on an assessment of the state of the science, the major process uncertainties exist for (1) pathogenic bacteria and virus viability kinetics and partitioning; (2) speciation and sorption of ionizable organic chemicals and metals; (3) microbial transformation kinetics and pathways, particularly anaerobic transformation of hazardous chemicals; (4) phytotransformation process kinetics and pathways; (5) abiotic redox transformation process kinetics and pathways; and (6) terrestrial biospheric cycling/storage/release of nitrogenous and carbonaceous greenhouse gases and nutrients. Consequently, these areas will constitute the major processes research foci for both terrestrial and aquatic systems.

As indicated in previous sections of this strategy, stressors other than pollutants must be assessed at various geographical and temporal scales, in various media, and in conjunction with pollutant stressors. To this end, one major focus of the effort to improve aquatic and terrestrial component stressor exposure modules must include the development and incorporation of those physical descriptors necessary to define "suitable habitat" (e.g., temperature, sediment deposition-scone transport, shear stress, riffles-pools, land forms, and distribution, "patchiners", corridors, edge-to-volume configurations, etc.). This requirement will necessitate a vigorous program to link geographic information system (GIS) technology to existing and developmental aquatic and terrestrial component exposure modules. It also will necessitate a comprehensive evaluation and upgrade of the hydrologic, hydraulic, and sediment transport algorithms in existing and developmental component modules, along with the pollutant transport and transformation process descriptions. Finally, in order to accelerate the development of these new multistressor aquatic and terrestrial component modules for both regulatory support application and for general framework incorporation, ORD initially will focus on linked, watershed response system modules, including associated terrestrial and groundwater components, and site screening modules.

3.3.3.2 Biogeochemical Processes

Model key land surface and surface water processes to describe the storage (sinks) or release (sources) of greenhouse gases, nutrients, organic carbon, etc., in the context of global change feedback analyses and regional ecosystem risk assessment

3.3.3.2.1 Rationale and Objectives

The internal cycling, storage, and intermedia exchanges of nitrogenic and carbonaceous greenhouse gases, particularly their net releases to or removal from the atmosphere, and the factors that determine the same are major unknowns relative to the projection of global climate change and any feedback effects that the terrestrial biosphere may impact thereon. In addition, nitrogen and, to a lesser extent, phosphorus cycling and storage within various land use categories is a major unknown relative to the ability to predict nutrient exports from these land forms to groundwater and surface aquatic systems at a watershed or regional scale, given the potential mix of nutrient inputs to these various land forms (i.e., natural and anthropogenic atmospheric nitrogen deposition, fertilizers, animal wastes, and biosolids).

The objectives of this research are to

- quantify the net carbon and nitrogen greenhouse gas fluxes between the terrestrial biosphere and the atmosphere as a function of selected land use changes and management practices;
- quantify and model carbon and nitrogen gas cycling, storage, and release from the terrestrial biosphere for coupling to an ESM for use in projecting long-term regional climate (precipitation) changes as part of the IPCC and CENR effort; and
- quantify and model nutrient storage and release form major land use categories (i.e., forests, row crops, pastures, etc.) as a function of total nutrient inputs and management practices.

3.3.3.2.2 Specific Research Foci

The specific research focus will be on

- carbon greenhouse gas fluxes in a boreal forest biome affected by fire;
- soil organic carbon cycling and CO_2 release to refine estimates of the carbon sequestration potential of various agricultural and silvicultural management practices (e.g., minimum tillage);
- a comprehensive soils biogeochemistry model, “S”, is being developed for linking to the developmental ESM to assess potential terrestrial biome feedback effects on simulated global climate change and to permit better, long-term regional precipitation projections (“S” will deal with both carbon and nitrogen cycles and release/storage and also will be investigated as a way to predict nitrogen breakthroughs and exports from various land use categories, as a function of total inputs and management.); and
- models to describe photochemical production of labile nitrogen in Southeastern estuarine waters.

3.3.3.3 Transport Properties and Processes for Organic and Inorganic Pollutants

Model key pollutant transport processes in soil, water, sediment, and plant systems for use in single- and multimedia exposure assessment models/modules

3.3.3.3.1 Rationale and Objectives

Before any defensible terrestrial or aquatic ecosystem exposure assessment can be conducted, key pollutant source-sink processes must be characterized, modeled, and integrated into the appropriate media exposure-risk assessment methodology (or general model framework). As indicated previously, a state-of-the-art assessment has identified those "most uncertain" pollutant transport processes to be addressed in this strategy as follows:

- understand, quantify, and model the speciation of complex molecules (organics and metal/nonmetal inorganics) in natural soil water and sediment water systems;
- quantify and model the sorption-desorption-complexation interactions of ionizable pollutants with natural mineral surfaces, humic-coated natural materials and dissolved organic matter; and
- expand, test, and link to selected media compartment exposure assessment models (or general framework) the SPARC computerized organic pollutant transport process parameter estimation expert system.

3.3.3.3.2 Specific Research Foci

Research will focus on

- the MINTEQ II Thermodynamic Database Update to provide defensible speciation projections for partitioning metals in soil-pore water and sediment-water systems;
- development of techniques to properly characterize the redox status of soil, aquifer, and sediment-water systems for speciation calculations;
- in situ measurement of organic pollutant speciation in soil water and sediment water systems via vibrational spectroscopy to characterize ionizable organic pollutant speciation as a function of pH for use in parameterizing and testing computational chemistry systems such as SPARC;
- characterizing the ion-binding sites and capacities for natural aggregate materials and dissolved organic matter to improve partitioning algorithms for complex organic pollutants and metals to soils and sediments;
- development of a general reactivity-partitioning model for environmental surfaces for organic and inorganic contaminants;
- characterizing the behavior and bioavailability of highly hydrophobic candidate organic endocrine-disrupting compounds in contaminated natural soils and sediments;
- upgrading and testing SPARC's ability (algorithms) to predict the physical-chemical transport properties of polar and charged organics; and
- integrating upgraded pollutant transport process algorithms into operational and developmental terrestrial and aquatic component exposure models.

3.3.3.4 Transformation Processes of Pollutants

Model key pollutant transformation processes in soil, sediment, water, and plant systems for direct use as sink-source algorithms in single- and multimedia pollutant exposure-risk assessment models/modules

3.3.3.4.1 Rationale and Objectives

The key transformation processes to be characterized, modeled, and incorporated into the aquatic and terrestrial ecosystem compartment exposure-risk assessment models (framework modules) are microbial transformations (both aerobic and anaerobic) and phytotransformation (plants and enzymes).

Specifically, the objectives of this research are to

- understand pathways and quantify and model the kinetics of previously uncharacterized sink-source processes for pollutants in soil-water and sediment-water systems, particularly microbial and phytotransformations (Emphasis is on anaerobic transformations of chlorinated aromatic compounds and aerobic transformations of PAHs and chlorinated aliphatics.);
- develop organometallic formation and degradation kinetics and pathways data for selected metals of concern, particularly mercury, arsenic, and lead; and
- characterize and model abiotic (heterogeneous) reductive transformation rates and pathways for selected classes of organic pollutants of concern to EPA.

3.3.3.4.2 Specific Foci

Specifically, research will focus on

- anaerobic microbial kinetics and pathways for organochlorines (i.e., selected endocrine-disrupting chemical [EDC] candidates and pesticides as benchmark chemicals);
- aAbiotic/enzymatic reduction of organic pollutants, using specific probe compounds representative of classes of organic chemicals of concern;
- degradation properties (rates and pathways) of chiral compounds, opening opportunities to tailored chiral products that are nonpersistent and of lower toxicity;
- assay techniques for characterizing phytotransformation activity of aquatic and terrestrial plants for organonitrogen, organochlorine, organophosphate, and organosulfur pollutants of concern; and
- incorporation of transformation kinetics algorithms into terrestrial and aquatic component exposure assessment models (framework modules).

3.3.3.5 Implementation

This research will be conducted almost exclusively by EPA researchers, much of it through internal research grants. Watershed response modeling will require some contract and interagency agreement support. Results from the grants program at the process level will be incorporated along with ORD-generated process algorithms whenever possible and appropriate.

3.3.3.6 Government Performance and Results Act Milestones

- **By 2000**, kinetics of contaminant release from sediment models to determine or predict the bioavailability and residue-based approaches for chemical stressor.
- **By 2002**, effects of sorption on biotic and abiotic transformation rates in sediments—produce prototype model(s) at the watershed scale integrating landscape conditions and biophysical and socioeconomic variables for application in different regions of the United States.
- **By 2003**, evaluate publicly available water flow and quality simulation models in terms of their ability to evaluate risks associated with various control technologies for wet weather flows in a watershed (shared with NRMRL).
- **By 2004**, provide next generation of water and soil transport and fate models to predict the distribution of chemical and other stressors.

3.3.4 Improving Effects Modeling

Improve stressor-response analyses and techniques to establish cause and effect relationships

3.3.4.1 Background

The use of the ecological risk assessment process as a foundation for environmental decision-making currently is limited by the science supporting the activities of problem formulation, analysis, and risk characterization. Research to improve knowledge of the ecosystem processes that will enhance effects modeling will reduce the scope of these limitations. In prioritizing areas of ecological effects research, ORD has identified the following scientific uncertainties as the focus of research for the next 5 years:

- identification of scientifically credible assessment endpoints that accurately reflect management goals and societal values;
- availability and use of measures of effects and measures of ecosystem characteristics to represent assessment endpoints adequately; and
- understanding of ecological processes, mechanisms, and relationships that support development of stressor-response analyses and cause-and-effect relationships.

Risk assessment endpoints must be ecologically relevant, susceptible to known or potential stressors, and represent management goals. Risk assessment endpoints directly influence the type, characteristics, and interpretation of data and information used for analyses and the scale and character of an assessment. Failures to properly define assessment endpoints often limit the usefulness of ecological risk assessments. Developing the proper linkages of assessment endpoints to the scale of a risk assessment is a significant challenge and requires an improved understanding of the relationships between levels of biological organization and the hierarchical relationships of ecosystem components and processes across space and time. Understanding relationships between risk assessment endpoints and the presence of multiple stressors is also a critical issue. The presence of multiple stressors in many ecological risk assessments requires the selection of assessment endpoints that respond differently to stressors to evaluate cumulative effects and to discriminate effects among stressor types. Multiple stressors may act at different spatial and temporal scales and levels of biological organization and require selection of an appropriate array of endpoints that capture both indirect and direct effects.

Although assessment endpoints must be defined in terms of measurable attributes, their selection does not depend on the ability to measure these attributes directly. In cases where the assessment endpoints cannot be measured directly, their response may be predicted based on responses of surrogate or similar entities (i.e., measures of effects). In addition, measures of ecosystem characteristics often are needed to improve the means of interpreting assessment endpoints or measures of effects. Methods to link assessment endpoints with measures of effects must be applied in a manner consistent with sound ecological principles. Empirical and process-based approaches for linking measures of effects to assessment endpoints are used to varying degrees depending on the scope of the assessment and the data and resources available. Empirical and process-based models can range from the use of uncertainty factors to the application of complex models that require extensive inputs. The development of improved empirical and process-based models is required to aid in extrapolating measures of effects to assessment endpoints. The development of decision trees for selecting modeling approaches and "standard" models or parameter sets to simplify comparisons among stressors and species, populations, communities, and ecosystems are also needed.

The focus of the research to be discussed in this section will be on understanding processes and developing models for determining the relationship between stressor levels and ecological effects.

3.3.4.2 Understanding and Predicting the Effects of Watershed and Regional Change

Develop methods and models to predict the ecological effects of human activities at the watershed and regional scales

3.3.4.2.1 Rationale and Objectives

Ecological risk assessments typically are conducted on single human-induced stressors (e.g., a single contaminant introduced into a stream) at a single level of biological organization. For toxicological issues, the biological organizations usually range from the cellular to the species (see Section 3.2). For ecological issues, populations of species, communities, and ecosystems may be added. The interaction of the biologic and abiotic components in ecosystems greatly increases the complexity of the assessment. Although endpoints are relatively easily described up to the population level, defining endpoints for ecosystems becomes much more challenging because concepts like health and sustainability often are introduced. At the larger scale, ecosystems are structurally and functionally integrated because of the interactions and exchange of energy and nutrients between the mosaic of terrestrial and aquatic components. As such, an understanding of how these systems respond to human activities requires research to be conducted in the context of the surrounding landscape from the watershed to regional scale. The research to be conducted by ORD includes studies to facilitate the prediction and extrapolation of the effects of real or potential changes in landscape characteristics on a variety of ecosystem endpoints of concern. Methods to evaluate the effects of future change and diagnose causes of responses to change will be developed. In addition, a number of studies on specific regional issues that require the integration of data across multiple systems will be conducted in various areas of the nation. These efforts will provide an opportunity to test ideas, develop methods, and address issues across a wide array of biogeographic regions.

3.3.4.2.2 Specific Research Foci

Watershed and Regional Responses

Research will be directed toward improving methods and models to understand linkages among ecosystem components within watersheds and regions and the degree to which landscape patterns affect the sustainability of ecosystems. These efforts will contribute to an improved ability to predict cumulative impacts and to diagnose causes of impairment. The ability to predict the response of systems at the watershed and regional scale to a variety of potential landscape changes will be an important objective. Scientific investigations will be conducted on (1) watershed structure/function relationships and the degree to which changing landscape patterns affect integrity and sustainability; (2) the extent to which cumulative impacts can be differentiated or partitioned among chemical, physical, and biological stressors; and (3) how effects are integrated across hierarchical scales. Understanding these relationships requires a knowledge of landscape component functions; relationships between location in the landscape and the sensitivity of ecosystems to stressors; and the effect of landscape pattern on the transfer of energy, materials, or populations across ecotones. Results of the research also are anticipated to improve understanding of diagnostic indicators of ecological sustainability.

Integrated Effects in the Mid-Atlantic Region

Regional and watershed research in the Mid-Atlantic region is focused on the development and application of methods to conduct integrated ecological resource assessments on regional spatial scales. The goals of this research are to (1) develop a framework that can be used to conduct integrated resource assessments across various levels of geographic scale, (2) evaluate the use of historical data as a means of testing the assessment process, (3) identify research gaps that must be addressed to reduce uncertainties in conducting such assessments, and (4) develop an information management system that can be used effectively and efficiently in future regional assessments. The experience gained from this research will be applied and transferred to other geographical areas to conduct these assessments more cost-effectively.

Predicting Effects in South Florida

Activities in the Everglades Agricultural Area (EAA), located south of Lake Okeechobee, utilize herbicides and pesticides for plant and animal control and fertilizers to promote yield. Drainage from the EAA is channeled through a series of canals into Biscayne Bay, the Gulf of Mexico, or Florida Bay. There is an increased awareness by the public and scientific communities of a mercury problem in South Florida. Warnings against eating gamefish have been issued, as concentrations of 0.5 to 1.5 ppm of mercury are common. In addition to the transport of mercury, herbicides, and pesticides, flows within the South Florida system contain nutrients in the form of nitrates and phosphates. If excessive nutrients are discharged into Florida Bay, the potential exists for impacting algal, phytoplankton, and submerged aquatic vegetation populations. Through these impacts to the system's plant communities, broader effects to biota including local finfish and shellfish populations are possible.

The objectives of this research are to develop the data and predictive mathematical models to assess the effects of mercury, herbicides, pesticides, and nutrients—alone or in combination—on stability of amphibian, reptilian, fish, bird, plant, and coral populations; diversity of communities; and the condition of the Florida Bay ecosystem. Relevant field data will be collected to develop four mechanistic, ecological models to assess and understand better the ecological conditions and their causes in South Florida estuaries and coastal waters. The four proposed models are (1) a population model of the relationship between reproductive success and endocrine disruptors; (2) an ecological model of pesticide and mercury flow and fate and their effects on biota; (3) a model of the nutrient dynamics in Florida Bay and the effects on trophic structure; and (4) a community model of UV-B, contaminant, and nutrient dynamics and their aggregate effects on coral assemblages.

Cumulative Effects on Pacific Northwest Estuarine Systems

The high rate of human population growth in the Pacific Northwest is subjecting estuaries and coastal watersheds to many anthropogenic stresses. The amount of this stress will continue to increase as population growth continues and the Northwest further develops economically. Activities that jeopardize the ecological sustainability of estuarine and coastal watershed resources include watershed alterations, such as urbanization and other land use changes, road construction, and agricultural and forestry practices. These activities result in increased nutrient and sediment loads, alteration, and loss of habitat, including elevated stream temperatures, pollution, exotic biotic introductions, and alterations in extreme natural events such as floods and disease or pest outbreaks. Determining the effects of stressors is complicated by the fact that they have different ecological effects and act at various, often overlapping, spatial and temporal scales.

The purpose of this research is to develop methods and models for predicting the cumulative effects of multiple stressors on ecologically and economically important estuarine assessment endpoints at multiple spatial and temporal scales. This involves (1) determining single and multiple stressor-response relationships, (2) developing spatially and temporally explicit sampling procedures and models, (3) quantifying the variability of multiple stressor effects, and (4) distinguishing multiple stressor effects from natural variability. The goal is to produce a framework, including a scientifically credible approach and set of analytical tools, to predict the combined effects of important stressors on the trajectory of ecological assessment endpoints over time.

Great Lakes Effect Modeling

The St. Lawrence, the Great Lakes, and associated drainage have been subjected to a wide array of stressors for several centuries. In response to previous degradation, The Great Lakes Water Quality Agreement calls for the restoration and maintenance of the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem. The governments of the United States and Canada, which provide joint oversight of the lakes, cite four general issues that encompass a broad array of problems and outline the major stressors on aquatic life and wildlife: (1) the loss of biodiversity and biological integrity; (2) degradation and loss of habitat, including tributary, near-shore, and coastal wetlands areas; (3) impacts of persistent toxic contaminants; and (4) eutrophication in certain areas. Because of the vast size of the Great Lakes, contrasting ecoregions and habitats, multiple stressors with different modes of action and behavior, stressor interactions, and numerous sources and media, the development of management strategies often has been hampered. Consistent with requirements of the Great Lakes Water Quality Agreement to develop a holistic, ecosystem approach for the management of the Great Lakes, the need to synthesize interdisciplinary information for forecasting capabilities has been recognized, and mathematical modeling has been accepted as an essential component of environmental management decision making. Research will be undertaken to develop, refine, apply, and verify mathematical ecosystem response models for the Great Lakes. Research will address uncertainties and validate model predictions for the stressors of greatest environmental concern, using field data specifically collected for such purposes. Uncertainties in predicting eutrophication, bioaccumulation, and ecosystem productivity will be emphasized.

3.3.4.3 Ecosystem Modeling

Develop methods and models to predict the effects of human activities on ecosystems

3.3.4.3.1 Rationale and Objectives

Although many improvements have been made over the last few decades, the Nation's freshwater, marine, and terrestrial ecosystems continue to be threatened by a variety of anthropogenic stressors. Although the effects of chemical stressors remain a significant issue in many waters, the effects of physical and biological disturbances are also widespread problems. The successful protection of freshwater and marine ecosystems depends on an understanding of the interactions and cumulative impacts of a complex mixture of stressors at various temporal and spatial scales. Within terrestrial ecosystems, understanding of the functioning and response of plants and the vegetative component to environmental stress is most limited. In the past, vegetation was considered to be an easily regenerated and manipulated natural resource that was relatively insensitive to environmental stress. However, understanding and concern for this basic component of the biosphere has changed, with effects of atmospherically mediated stressors, such as regional air pollution and climate change, and the interaction of these stressors with land and resource use as primary concerns.

Based on an evaluation of the state-of-the-science, as well as the scientific and ecological risk assessment uncertainties identified in CENR and EPA strategic plans, process and modeling effects research undertaken by ORD will be directed towards the following areas: (1) characterizing and predicting the responses of ecosystems to physical, biological, and chemical stressors; (2) advancing techniques to extrapolate and interpret effects across levels of biological organization; and (3) developing ways to measure the integrity and sustainability of ecosystems and diagnose causes of degradation. This research will involve the development of sound methods and models to screen, diagnose, and predict ecological effects for both prospective and retrospective ecological risk assessments.

3.3.4.3.2 Specific Research Foci

Freshwater Ecosystems

The goal of this research is to understand how stressors modify constraints on aquatic ecosystem structure and function, to reduce uncertainties in effects extrapolations from the laboratory to the field, and to develop and evaluate measurement techniques for components and processes that describe the condition of aquatic ecosystems. Much of the stressor-effects data used in ecological risk assessments is obtained from laboratory tests and presents significant extrapolation challenges when assessment endpoints are at the population, community, or ecosystem level. Whole-ecosystem studies or studies of intact ecosystem components rarely are performed because of high cost and time commitments. In addition, the high degree of variability among natural ecosystems makes extrapolations from examined systems to other systems difficult. In turn, these uncertainties impact chemical ecological effect characterizations and risk assessments, such as those performed by the Office of Pesticide Programs and the Office of Water, as well as the development and application of the Office of Water's biological and ecological criteria, which are designed to protect aquatic communities and ecosystems. The use of appropriate ecological indicators to characterize and quantify effects reflects a need that impacts all of EPA's program and regional offices and their ability to formulate risk assessment problems, interpret effects characterizations, and evaluate the utility of risk-based environmental management decisions.

Research will be designed to advance an understanding of population, community, and ecosystem organization and dynamics to improve predictive components of prospective risk assessments, interpretations within retrospective assessments, and the linkage of ecological indicators to measures of effects and ecosystem characteristics in a risk assessment context. Research at the population, community, and ecosystem level will incorporate modeling, laboratory investigations, and field studies. Field studies will involve intensive study sites within a multiwatershed design and will result in models that link watershed function to landscape effects on wetlands and the near-shore environment of large water bodies.

Marine Ecosystems

The goal of this research is to develop models for extrapolating and interpreting effects across levels of biological organization.

ORD is responsible, in part, for conducting research in the estuaries and coastal waters of the nation to provide rigorous, quantifiable indicators that will allow managers to develop scientifically sound environmental regulations. The results of this research will provide the critical scientific information necessary for environmental managers to address two fundamental questions: (1) what is the current ecological integrity of an estuarine water body? and (2) what effect will specific changes in anthropogenic inputs have on that condition? This research effort will develop the theoretical framework to characterize, quantify, and predict the ecological integrity of estuarine and marine ecosystems at the management unit scale of a watershed sub-basin. This will be accomplished through an integrated approach capable of describing the complexity within an estuarine ecosystem. Within this framework, key structural and functional components will be quantified for coastal wetlands, fish habitats, benthic communities, and the overall trophic structure of estuaries. The physiological, pathological, and reproductive systems of key estuarine organisms will be characterized to assist in predicting their responses to stressors. For the concept of ecological integrity to be useful in a scientific or regulatory context, it must be quantified relative to an expected condition or reference state. Consequently, the research effort also will examine the structural and functional basis for defining ecosystem similarity, both spatially and temporally.

Natural and anthropogenic stressors affect estuarine and coastal environments at all levels of organization, yet effects research historically has focused on responses at lower levels. However, assessment endpoints for ecological risk assessments are typically at the population, community, or ecosystem level. Consequently, there is a need to improve the means of extrapolating effects across levels of biological organization. Efforts to improve the means of predicting population-level responses will be accomplished by explicitly incorporating bioassay data into population models. Stressors also can act as strong selective agents in an evolutionary context by eliciting compensatory mechanisms that allow a population to persist in the stressed environment. These compensatory mechanisms, expressed at a range of biological organization from molecular adaptation to life history strategy alterations, will be explicitly incorporated into population models to improve the means of forecasting ecological effects.

Although chemical stressors remain a concern, nutrient enrichment, climate change, and other types of habitat alteration are significant current and future stressors of coastal ecosystems. As a result, research is needed to better characterize causal linkages between physical, biological, and chemical stressors and coastal ecosystem responses and to develop the means of quantifying future coastal zone change. Research will identify the factors that regulate the way in which nutrient enrichment and eutrophication are expressed in estuarine ecosystems. The effort will lead to community/ecosystem mechanistic mathematical models to assess effects of nutrient enrichment on selected system endpoints such as (1) hypoxia/anoxia; (2) loss of submerged aquatic vegetation (SAV) habitat through mechanisms dependent on enrichment; (3) increases in nuisance and toxic phytoplankton blooms; (4) qualitative and quantitative changes in linkage between primary and secondary productivity; and (5) the relationships of trophic cascading and nutrient supplies, as effects of the estuarine eutrophication process. Research addressing effects on SAV will be emphasized because SAV provides essential nursery habitats for a wide variety of economically important fish and shellfish, stabilizes sediments, and reduces erosion of shorelines. The widespread loss of SAV communities worldwide has been attributed to increased water turbidity caused by dredging and runoff, increased nutrient loading and algal production, and direct physical damage from recreational activities. Potential long-term effects from global climate change are also plausible.

Terrestrial Ecosystems

Experimental observations of effects at higher levels of biological hierarchy (i.e., community and ecosystem) or increasing biological complexity (species diversity, stand structure, and presence of trophic functional groups) are limited. Invariably, the data from one set of experiments is extrapolated to predict the species' response nationwide. This often includes extrapolating the response in natural environments with all the concomitant moisture, nutrient, and competitive stresses that may be in place across the spatial and temporal extent of the species in question, even though the data sets do not include these conditions. In addition, only a very small representation of species is ever studied, yet frequently these data are used to represent all vegetation, crop, or forest tree species. At ecosystem and landscape scales, even less information is available to predict changes with changing pollutant exposure scenarios or changing global climate. An approach is required to develop the necessary linkages to extrapolate experimental data taken at the individual level, often in artificial conditions, to suggest changes occurring in more complex native environments to individuals or populations. Equal attention is needed to understand changes at higher scales of biological organization, as well as landscapes. A multifaceted, interactive research approach is necessary, including experimental and modeling components, with each informing the other. The objective of this research is to provide a scientifically sound understanding of error sources in extrapolating from individual responses to ecosystem responses and across geographic scales. Additionally, a mechanistic knowledge of the ecosystem processes is needed to predict to multiple environmental stressors. The research will involve experimental, modeling, and field studies at a range of scales from the individual to the landscape.

Compared to above-ground components of terrestrial systems, much less is known about the belowground area. Yet there is increasing evidence that the rhizosphere may play a critical role in the response of vegetative systems to stress. For example, ORD research has shown that ozone stress may be first manifest in the rhizosphere. Increasing the understanding of the role of the rhizosphere appears to offer promise for improving the capability to assess the overall condition of terrestrial systems and to predict their response to stress. As the rhizosphere is the interface between the primary carbon processes (i.e., aboveground carbon acquisition) and primary nutrient and water processes (i.e., belowground nutrient and water acquisition), it is essential to understand how specific stressors will affect this interface. The goal of the rhizosphere research is to determine the effects of atmospheric pollutants and global change components (e.g., CO_2, precipitation, temperature, etc.) on key processes in controlling the exchange of carbon and nitrogen between the root/soil and the plant canopy. For example, elevated CO_2 increases fine root growth and fine root life span. In contrast, elevated ozone decreases fine root growth and is hypothesized to decrease fine root size span, as it decreases fine root carbohydrate levels. In situ techniques and microbiological and molecular (DNA fingerprinting—see Section 3.2) approaches will be applied. Intensive sampling in terracosms and at field sites will provide the data necessary to parameterize ecosystem models that are used to develop understanding and prediction of the multiple stress effects on carbon and nitrogen cycling in forest ecosystems.

3.3.4.4 Ecotoxicology

Develop methods and models to predict the effects of chemical stressors on aquatic organisms and wildlife

3.3.4.4.1 Rationale and Objectives

ORD conducts research to provide scientific information on the toxic effects of chemical stressors to aquatic life and wildlife to reduce uncertainty in risk assessments and support risk management options. The research is designed to develop a mechanistic understanding to establish cause and effect relationships for chemical stressors already in the environment and to predict responses to stressors not yet present or released. As a result, research involves the development of sound methods and models to screen, diagnose, and predict ecological effects in both prospective and retrospective ecological risk assessments. Effects research undertaken is designed to improve knowledge bases, mechanistic understandings, and techniques in the context of the problem formulation, analysis, and risk characterization phases of ecological risk assessments.

Ecological risk assessments of chemical stressors typically are confronted with a lack of toxicity data for either the chemical or species of concern. Owing to the complexity of most environmental problems, and because of limited testing capability, there is also a need to extrapolate existing information to untested species or exposure scenarios. Although understanding of the lethal effects of xenobiotics to aquatic organisms continues to expand and supports improved extrapolations across chemicals and species, there is significant uncertainty when reproductive and developmental endpoints are considered (i.e., when the influence of environmental factors on the toxicity of single chemicals and mixtures must be taken into account). In addition, the quantitative extrapolation of adverse reproductive and developmental effects at the organismal-level to population-level responses remains a challenge in ecological risk assessments.

Based on an evaluation of the state-of-the-science, as well as the scientific and ecological risk assessment uncertainties identified in the CENR and EPA strategic plans, ecotoxicology research will be focused in the following areas: (1) understanding and predicting basic biological and chemical mechanisms of toxicity; (2) measuring and predicting the uptake, distribution, and elimination of xenobiotics in aquatic life and wildlife; (3) predicting reproductive and developmental effects of chemical stressors; and (4) predicting the effects of mixtures or multiple stressors in water and sediment.

3.3.4.4.2 Specific Research Foci

Biochemical and Cellular Toxicology

The goal of this research is to advance understanding of biochemical and cellular toxicodynamics and xenobiotic metabolism to reduce uncertainties in extrapolating toxic effects across chemicals and species. In the field of environmental toxicology, and especially aquatic toxicology, quantitative structure-activity relationships (QSARs) have developed as scientifically credible tools for predicting the acute, and in some instances subchronic, toxicity of chemicals when little or no empirical data are available. In addition to the use of these predictive toxicity models, there also has been an increased call for the complementary use of in vitro or short-term in vivo experimental models to provide the ecotoxicological data required for preliminary or screening-level effects characterizations. Challenges to improve the use of predictive models and screening assays for either "chemical" or species extrapolations center on uncertainties in understanding mechanisms of chemical toxicity and xenobiotic metabolism, as well as the linkage of cellular or biochemical effects and processes to organismal-level responses. Tissue, cellular, and subcellular models will be used in research designed to explore the relationships between chemical structures and properties and biological activity. A significant challenge to the research will be to link biochemical and molecular biological responses to cellular and subcellular structure and to the intact organism. Metabolism research will be undertaken to help expand understanding of specific mechanisms of action and bioaccumulation of xenobiotics, with a bias to experimental designs that further the means of relating kinetics of metabolic reactions to chemical structure.

Toxicokinetics and Dosimetry

The focus of this research will be to develop physiologically based toxicokinetic models as components of a biologically based approach to reducing uncertainties in species extrapolation and the interpretation of toxic effects. Toxicokinetic and dosimetry research is concerned principally with the uptake and disposition of chemical stressors by individual organisms, recognizing that, in many cases, this uptake is part of an extended chain of events involving entire food webs. The quantitative nature of toxicokinetics lends itself to the development of mathematical models that formalize, simplify, and codify complex information that can be used to extrapolate limited effects information. Research will be conducted in support of model development and as a means of evaluating model performance. Descriptive research will be undertaken frequently in advance of mechanistic research to define the system under study and to collect an empirical data set that then becomes the basis for subsequent development of mechanistic hypotheses. Metabolic biotransformation and bioavailability have been identified as scientific uncertainties that represent the highest priority areas of research for several EPA program offices. Metabolism research will be directed toward developing the capability to model the rates of parent compound disappearance and formation of biotransformation products. An emphasis will be placed on compounds that undergo metabolism to more reactive species, although consideration will also be given to metabolism as a pathway for chemical elimination (particularly in the case of bioaccumulative organic compounds). Bioavailability research initially will focus on the dietary uptake of hydrophobic organic compounds, followed by studies on the waterborne and dietary uptake of metals. Efforts will be initiated to expand modeling activities to include other taxa, including piscivorous wildlife, invertebrates, amphibians, and marine mammals.

Reproductive and Developmental Toxicology

Research efforts in this area will involve investigations of the reproductive and developmental effects of xenobiotics on aquatic life and wildlife to reduce uncertainties in predicting effects and interpreting population and community level responses. An increased mechanistic understanding of developmental and reproductive toxicants at the organismal level is needed to support the relevancy of in vitro and QSAR-based screening assays designed to identify potentially potent compounds. An understanding of those organismal-level attributes and processes that primarily constrain population dynamics is also needed to ensure that relevant toxicological responses are addressed. ORD has a long history in developing aquatic toxicity testing methods and techniques that are used nationally and internationally. Experience has been gained with invertebrates, small aquarium fish, and large cold-water fish. However, studies with species for which extensive molecular biological information is available (e.g., zebra fish, medaka) are limited, and techniques and basic physiological and toxicological information is limited for species representative of declining amphibian and mollusk populations. Studies and bioassay approaches specifically designed to optimize exposures within developmental windows controlled by specific hormonal axes and to properly identify and quantify associated adverse effects are not available. To address these issues, a systematic evaluation of compounds known or suspected to disrupt endocrine function through interaction with the aryl hydrocarbon, estrogen, androgen, thyroid, and retenoic acid receptors will be evaluated in a variety of fish species. In addition, amphibian species (e.g., *Rana pipiens* and *Xenopus laevis*) will be used to embark on a systematic examination of comparative physiological and toxicological responses to provide more detailed insights into the strengths and weaknesses of different models in terms of mechanistic and ecological relevancy.

Ecotoxicity Characterization

The goal of this research effort is to investigate the interaction of chemical and nonchemical stressors on aquatic life to reduce uncertainties in predicting the joint action of stressors and diagnosing cause and effect relationships in impacted ecosystems. Knowledge gaps that limit the advancement of aquatic life and sediment criteria, and that reflect limitations in current scientific understanding, can be grouped into four broad categories that include (1) interactions of physical and chemical factors, (2) organismal variability, (3) dose characterization, and (4) chemical mixture interactions. Future research will build on the existing ecotoxicological knowledge base to address specific high-priority topics that reflect important scientific uncertainties that are relevant to classes of ecological risk assessments that confront EPA. Research will address the need for assessment approaches that integrate aquatic life effects and stressor interactions within the water column and sediments. Research to be undertaken to improve understanding in the areas of physical/chemical interactions will include studies that address metal bioavailability and toxicity and the role of UV in photoactivating organic compounds. Dose-characterization research will improve the means of interpreting the adverse effects of superhydrophobic chemicals in the context of measured or predicted organismal or tissue bioaccumulation. Chemical mixture research will concentrate on the completion of toxicity identification evaluation techniques and be followed by efforts to improve predictive techniques. Efforts also will be maintained to ensure that the results of ecotoxicological studies are available to the risk assessment communities at the federal, state, and local levels through the ECOTOX database.

3.3.4.5 Implementation

The majority of this research will be conducted through the in-house research of federal scientists. Contract support to in-house researchers is directed primarily towards terrestrial ecosystem, Pacific Northwest, and Great Lakes watershed research. The ECOTOX database also is supported by contract assistance. A limited number of cooperative and interagency agreements complement the research conducted in the Pacific Northwest. Research grants on related projects that will contribute to these areas of science include the joint National Science Foundation (NSF)/EPA solicitations on water and watersheds.

3.3.4.6 Government Performance and Results Act Milestones

This research provides results that will contribute to and support the completion of the following GPRA milestones.

- **By 1999**, develop indicators to describe condition and exposure assessment in terrestrial and aquatic wildlife.
- **By 2000**, evaluate diagnostic application of indicators in local- and regional-scale assessments.
- **By 2001**, develop and apply indicator methods to detect exposures of wildlife to compounds that interact with the endocrine system: develop an empirical approach for studies of prairie pothole wetlands to determine the prioritization of restoration areas; develop a comparative risk-based approach at the landscape level for prioritizing wetland restoration sites; publish a complete evaluation of a multitiered, ecological monitoring system for the Mid-Atlantic region of the United States and its applicability to other areas of the country; complete an assessment approach, linking landscape indicators to models of future landscape change; and publish aquatic and terrestrial indicator methods.
- **By 2002**, evaluate indicator methods for endocrine disruptors at a local "source-based scale": evaluate wetland classification in the landscape; quantify wetland variability within specific geographic and land use settings; develop methods to characterize reference conditions for wetlands populations; determine environmental indicators for characterizing structure and function of wetlands along a gradient of environmental disturbance; and provide indicators of habitat suitability, landscape-level biotic processes, water resources, hydrologic processes, and terrestrial productivity for measuring the vulnerability of multiscale landscapes to change from multiple stressors.
- **By 2003**, apply ecological indicator methods for endocrine disruptors at regional scales: develop, apply, and evaluate the next generation of biological indicators that are most applicable to measure the success of water quality policies on freshwater and estuarine system condition and issue recommendations for their use and interpretation; and provide multilandscape indicator assessment techniques to determine relative condition of ecological resources at multiple scales.
- **By 2004**, develop methods and models to identify hazards and estimate dose-response actions specifically related to synergistic action of endocrine disruptor chemicals.

3.4 Assessment of Ecological Risk

Development of guidelines, assessments, and methods that quantify risks to ecosystems from multiple stressors at multiple scales and multiple endpoints.

3.4.1 Background

Since the 1970s, EPA has implemented a host of environmental statutes (e.g., Clean Air Act [CAA], Clean Water Act [CWA], Toxic Substances Control Act [TSCA]). Using an "end of the pipe" regulatory approach, releases to the environment have been significantly reduced from smokestacks, wastewater treatment facilities, and solid and hazardous wastes. As a result, EPA has made significant strides in reducing point source pollutant releases, to such an extent that regional and global scale problems, including habitat alteration, loss of biodiversity, climate change, and land-use changes, are now recognized as greater risks to ecosystems than site-specific problems (EPA, 1987).

The early 1980s saw both the emergence of risk assessment as a regulatory paradigm (National Research Council [NRC], 1983) and the first widespread use of ecological impacts to influence regulatory and policy decisions. The use of ecological information for decision making has expanded slowly through the 1980s, as illustrated by the regulation of diazinon based on impacts to birds, the adverse impacts of acid deposition on lakes and forests, and the damaging effects of ozone on crops. In the middle to late 1980s, tools and methods for conducting ecological risk assessments began to be standardized with the publication of the Ambient Water Quality Criteria methodology (EPA, 1985), the pesticides program's Standard Evaluation Procedures (EPA, 1986), and Superfund's Environmental Evaluation Manual (EPA, 1989).

The EPA's Science Advisory Board (SAB) report, titled *Future Risk: Research Strategies for the 1990s* (1989), emphasized the need for a fundamental shift in EPA's approach to environmental protection and challenged ORD to provide leadership in the area of ecosystem science. This report provided the impetus to shift the approach previously used in ecological assessments by focusing on the resources at risk and their composition within a landscape, multiple stressors, and multiple assessment endpoints. In 1992, EPA published the Ecological Risk Assessment Framework as the first statement of principles for ecological risk assessment (EPA, 1992) and, in 1996, published the first draft of the Ecological Risk Assessment Guidelines (EPA, 1996). These documents not only describe methods for conducting the more conventional single-species, chemical-based risk assessment, but they also describe techniques for assessing risks to ecosystems from multiple stressors and multiple endpoints. With the publication of these important documents came the need to create an organization that will focus on enhancing EPA's ability to do better ecological assessments. This is the goal of the NCEA within ORD.

This strategic plan recognizes the need to advance the science of multiple-scale, multiple-stressor, and multiple-endpoint ecological assessments. This will be accomplished by emphasizing research in three areas:

(1) developing risk assessment guidance,
(2) performing risk assessments, and
(3) conducting research on methods.

The ability to assess risks to ecosystems must be based on a knowledge of ecosystem behavior, and herein may lie the greatest risk to ecosystems: lack of knowledge of how ecosystems respond to multiple stressors. Short-lived stressors may produce transient and frequently immeasurable effects. The ecological impact of stressors like acid precipitation and global warming is only beginning to be understood, and the ability to assess the impacts to ecosystems requires that there be research on ecosystem behavior. Thus, the other elements of this strategy—effects research and research on ecological exposure, models, and monitoring—are necessary components of ecosystem-level assessments. Likewise, the problem formulation phase of the risk assessment helps direct the scope and nature of the research being conducted by the other ORD laboratories. The outcome of the risk assessment, what is at risk and at what level it should be protected to ensure ecological sustainability, is an essential conjunction of risk assessment and risk management research.

3.4.2 Ecological Risk Assessment Guidelines

Develop risk assessment guidelines to improve and standardize ecological risk assessments within and outside EPA

3.4.2.1 Rationale and Objectives

The development and publication of risk assessment guidelines is a major function of EPA. The development of guidelines is managed by the Risk Assessment Forum, an interagency forum of risk assessors, residing within NCEA. Risk assessment guidelines are important documents at EPA because they require risk assessors to follow standard methods in conducting risk assessments. Using the guidelines enables the risk managers to focus on ways to reduce or ameliorate the risk, rather than debating the technical merits of the risk assessment.

The development of risk assessment guidelines, especially ecological, is a dynamic process, involving many different disciplines, perspectives, and stakeholders. The refinement of existing ecological risk assessment guidelines and the development of new guidelines are major components of NCEA's ecological research strategy.

3.4.2.2 Specific Focus

3.4.2.2.1 Guidelines Development

Proposed guidelines were published in the *Federal Register* on September 9, 1996. After further revision, final guidelines will be published by the fall of 1997. The proposed guidelines are written as a broad-based expansion of principles contained in an earlier report *(Framework for Ecological Risk Assessment* [EPA, 1992a]). A follow-on activity is to prepare more specific guidance on particular ecological risk assessment topics. A high priority will be to develop place-based guidelines for those assessments that focus on a place at risk such as a watershed, a Superfund site, or some other biogeographically defined area. As with guidelines development, the preparation of specific guidance will be a cross-program effort conducted under the auspices of the Risk Assessment Forum. After the guidelines have been finalized, one or more cross-agency colloquia will be held to identify and prioritize topics for specific guidance. Next, teams will be formed to develop the guidance documents. Finally, the guidance documents will be peer reviewed and published.

3.4.2.2.2 Ecological Values

Although EPA's mission is to protect both human health and the environment, the focus historically has been on human health effects. A potential barrier to additional emphasis on ecological risks is a lack of consensus on what EPA values about ecological systems. Recently, a multiprogram work group identified a common set of agency-wide ecological goals and objectives that could be used by EPA risk managers and decision makers (EPA, 1997). ORD proposes to build on this project by obtaining the additional EPA review and consensus necessary to finalize the objectives and to begin the process of defining the range of outcomes for an endpoint (i.e., providing bounding estimates for acceptable and unacceptable effects). This effort could be the first step in a process of developing EPA-wide risk management guidelines that consider additional issues such as valuation of ecological systems, cost-benefit analysis, risk communication and perception, and stakeholder involvement in the risk assessment process. Providing guidance for risk managers on the use of ecological risk assessment information should be highly effective in advancing the consideration of ecological risks in decision making at the EPA.

3.4.2.2.3 Training and Consultation

Development of a training course for ecological risk assessment is a logical follow-on to the anticipated publication of final EPA-wide ecological risk assessment. A training course can strengthen the use of ecological risk assessment approaches across EPA and draw on the experiences of EPA risk assessors to identify significant issues and improve the ecological risk assessment process. Development of the training materials will begin with an informal survey of client needs and interests, followed by development of a course outline. A critical element for a successful course is the preparation of a range of ecological risk assessment case studies that can help tailor the course to a particular audience (e.g., Superfund, pesticides, etc.). Course materials will receive periodic review during development to ensure that the course will be relevant and useful to EPA's clients.

3.4.3 Assessments

Conduct ecological risk assessments at real places on special problems, and for important chemicals

3.4.3.1 Rationale and Objectives

Assessments conducted by ORD are selected because they meet one of the following criteria: they offer opportunities to advance the state of science, they are unusually important in that they represent important cross-program and interagency problems (e.g., dioxin, invasive species, global climate change), or the risk assessment may lead to new methods and procedures in assessing risks to ecological systems. Specific assessments may be organized around a set of ecological receptors that are at risk at a particular place (e.g., a watershed), a chemical that is known to pose major risks to ecological resources, or a biological stressor that poses risks. Decisions to conduct a risk assessment are made in the open, with the objective being to "make a difference" in conducting the assessment.

3.4.3.2 Specific Focus

3.4.3.2.1 Place-Based Ecological Risk Assessments

EPA has placed increased emphasis on community and place-based approaches to environmental management. These efforts represent a fundamental change from traditional single-media-based approaches for environmental regulation to a concern for the impact of multiple stressors over a broad range of spatial scales. The purpose of place-based research is to develop and demonstrate methods to assess the impact of multiple chemical, physical, and biological stressors at several different ecological scales. The way communities, ecosystems, and entire ecosystems respond to stress will be studied. Research may be able to define the "acceptable" impacts on ecosystems, including the watershed scale significance of stressors and management actions. The research will develop and demonstrate techniques and methods to quantify uncertainties associated with risk assessment.

Watersheds. ORD is applying the theoretical principles outlined in the Ecological Risk Assessment Guidelines to improve decision making in five watersheds. These ecological risk assessments were undertaken to address local or state concerns and to analyze stressors and resulting ecological effects. This approach applies the scientific principles espoused by the guidelines for the benefit of local human and ecological communities. Evaluating these demonstrations will enable improvements in the methods of place-based risk assessments. Simultaneously, the approach brings numerous organizations together to address and analyze an environmental problem and stimulates public awareness and participation in decision making for reducing ecological risks.

The five watershed level ecological risk assessment case study sites are

(1) ***Big Darby Creek, OH***. A watershed relatively free of pollution that is highly valued for its scenic beauty, its high water quality, and for recreational opportunities.

(2) ***Clinch Valley Watershed, VA***. The assemblage of fish and freshwater mussel species in the rivers in this watershed is among the most diverse in North America.

(3) ***Middle Platte River Wetlands, NE***. The Platte River provides water for agricultural irrigation, electric power production, recreation, fish, wildlife, and community and industrial water supplies.

(4) ***Waquoit Bay Estuary, MA***. A shallow Cape Cod estuary fed by groundwater and freshwater streams is prized by residents and visitors for its aesthetic beauty and recreational opportunities.

(5) ***Middle Snake River, ID***. The west-central Snake River plain of southern Idaho is the most degraded stream reach of the Snake River.

All five watershed case studies have proceeded to the problem-formulation stage and were presented to the SAB for review in June 1996. The next phase will be the analysis of risks based on problem formulation.

Large Scale Place-Based Assessments. Complementing the watershed studies are larger scale place-based studies. These studies are important for developing additional guidance on increasingly complex environmental problems. Such studies include both chemical-specific and multiple-stressor assessments.

- ***Region X Assessment***. In addition, to these five watershed case studies, ORD is working with Region X to apply the ecological risk assessment paradigm and to build an ecological information management system database for the river basins that include the entire state of Idaho. This system will develop a streamlined process that can be used to quantify total maximum daily pollutant loadings at multiple spatial scales.
- ***Mid-Atlantic Integrated Assessment***. In conjunction with all ORD laboratories and the interagency Committee on Environment and Natural Resources, an integrated assessment of the Mid-Atlantic area will be conducted. The first effort will be the development of a "state-of-the-region" report on the condition of the ecological resources and the magnitude and extent of stressors in the region. The role of climate change as an exacerbating influence on other stressors will be a major component of this assessment.

3.4.3.2.2 Chemical-Based Risk Assessments

Although EPA is moving towards implementing community or place-based approaches to environmental protection, chemical-based assessments are still important for some of the program offices, and there still will be the need to improve the science in assessing the risks from chemicals. Assessment methods for chemicals will, however, require a change in emphasis from that of a chemical-by-chemical approach to one emphasizing (1) methods to address chemical mixtures, (2) methods to address cumulative risks from combinations of chemical and nonchemical stressors, (3) methods that can be used to prioritize places and systems for more intensive work, and (4) methods to place impacts of chemicals in a landscape perspective. The basis for risk assessment from single-chemical, single-species is well developed, but more work is needed in moving to the higher levels of biological organization: single species, populations, communities, and ecosystems. One of the most pressing questions is how can ecotoxicological information from a single surrogate test species in a single test media be extrapolated to ecosystem-scale risks, if indeed it can.

The selection of chemicals to assess will be driven by (1) multimedia, multiprogram, or contentious issues; (2) assessments that provide examples or prototypes or allow for methodology development; and (3) assessments that provide the opportunity to improve the state-of-the-art in EPA's program offices and regions through technology transfer and support. Considering these criteria, strong candidates for ecological risk assessments include dioxin and endocrine-disrupting chemicals. Chemical assessments for these types of chemicals include aspects of addressing individual chemicals, as well as complex mixtures.

An important chemical-based activity will be the inclusion of ecotoxicology data in the Integrated Risk Information System (IRIS). This managed database has become an important reference source for chemical-based risk assessments and is widely used throughout EPA and other federal agencies and in the private sector as a peer-reviewed source of the most important information on the fate and effects of toxic chemicals. The database is now available via the Internet.

3.4.3.2.3 Special Ecological Assessments

There is a growing concern for the need to understand and assess important ecological issues that transcend the chemical-based or place-based approaches. Some of these multiple-stressor issues involve chemicals and places and include such things as global climate change, habitat loss, acid deposition, a worldwide decrease in biological diversity, and the ecological impacts of xenobiotic compounds such as endocrine disruptors. These and other regional- and global-scale problems, such as non-point source pollution, may present greater risks to public and environmental health than specific chemicals alone (EPA, 1987). As part of NCEA's mission to advance the science of risk assessment, it will, in conjunction with the other ORD labs, conduct assessments on important ecological issues. Some of the more important special assessments are identified here.

Acid Precipitation. Since 1990, monitoring networks have provided new data that clarify trends in deposition that have improved the understanding of the relationship among emissions, deposition, and effects. Improved models enable the reconstruction of historical conditions and project future scenarios. As a result of these developments, there is a better understanding of the relationship between sulfur and nitrogen emissions and acid deposition and its effects. Title IX of the CAA Amendments requires the National Acidic Precipitation Assessment Program (NAPAP) to prepare a scientific assessment of the current state of knowledge of acid precipitation and its effects. Staff will be assigned to NAPAP interagency team responsible for conducting a preliminary assessment in 1996 and a more thorough assessment for the year 2000. The study will focus on the assessment of improvements in aquatic and terrestrial ecosystems resulting from reductions in sulfur emissions.

Disease-Causing Shrimp Viruses. The worldwide shrimp industry has grown at a tremendous rate since the 1950s, largely because of the increase in shrimp aquaculture around the world. Along with this expansion, there has been an increase in the occurrence of disease-causing shrimp viruses, which is causing catastrophic mortalities and economic losses throughout this worldwide industry, including the U.S. shrimp aquaculture industry. The threat of these viruses to shrimp aquaculture is well known. However, there is little or no information on the potential impact of these viruses on wild shrimp fisheries. In response to the growing concerns for pathogenic shrimp viruses, ORD is working on a coordinated government effort to conduct an interagency assessment to deal with the impact of disease-causing shrimp viruses on the wild stocks and on shrimp aquaculture, importation, and processing industries. The NCEA staff are leading the effort to define the problem and frame the boundaries of the risk assessment. The assessment will eventually be used to control the viruses and protect the shrimp aquaculture industry.

Regional Vulnerabilities to Global Climate Change. ORD's Global Change Research Program (GCRP) will focus on integrated assessments of the potential ecological risks of climate change on coastal, freshwater, and terrestrial ecosystems from different regions throughout the United States, and it will extend the analysis to include implications for human health. The direct impacts, such as the increased frequency and intensity of heat waves, hurricanes, and storms, will have significant implications for environmental equity concerns—in the United States, often the elderly, poor, infirm, or mentally ill people suffer the most from extreme weather events. The goal of this project will be to identify the patterns of human health impacts caused by this type of extreme weather event and develop a plan to reduce the risk of similar damage happening in the future. The indirect impacts of climate change on human health are those that are mediated through ecological systems that may be impacted or altered with global climate change, namely, vector-borne diseases, such as encephalitis. Alterations in the patterns of temperature and precipitation will have impacts on the ecologies of both the vector host (mainly mosquitos), as well as on the parasite or pathogen (mainly arboviruses in the case of encephalitis).

Assessment of Biodiversity Loss. There is a worldwide concern about the loss of biodiversity. For example, frog and toad populations throughout the world have long been used by scientists as biological indicators of environmental concerns. The rapid decline of frog species worldwide has been associated with a variety of environmental degradation factors, such as habitat loss and fragmentation, chemical pollutants, increased UV radiation, and acidic precipitation. Thus, frog population declines may be a harbinger for environmental degradation. Recently, severely malformed frogs have been reported in wetlands areas in the Midwestern United States and in Canada. A variety of frog species have been found with deformities. Deformities of the hind limbs (e.g., missing limbs, extra limbs, bony limb-like protrusions), other muscular and digit deformities, and deformities of the eye and central nervous system have been noted. Although exact causes have not yet been identified, many theories exist as to the increase in the observed frequency of these deformities. Thus, the fundamental question becomes, what is causing the increase in the observed frequency of such deformities in frog populations?

Another concern exists for the loss of neotropical migratory bird species that breed in North America and over-winter in Central and South America. A number of species are showing a significant decline in their breeding populations, and the cause of the decline is not clear. It may be a combination of factors, including habitat loss and fragmentation, excess UV radiation, endocrine-like chemicals, decline in insect numbers (an important food for bird fledglings), or other causes of unknown origin. As with amphibians, these birds are considered barometers of environmental quality.

ORD will conduct an ecological risk assessment of the environmental factors contributing to the decline in amphibian and neotropical bird populations. The primary focus will be to identify the problem using current guidelines for ecological risk assessment.

3.4.4 Risk Assessment Methods Research

Develop new methods to conduct place-based, multiple-stressor assessments

3.4.4.1 Rationale and Objectives

Considerable progress has been made in assessing the ecological risks from the most egregious forms of pollution, such as an area devastated around an industrial plant, pesticides and toxic chemicals released into the environment, and similar problems where the cause-effect relationship is well understood. The predominant method of ecological risk assessment uses what is known as the "quotient method". With this method, the hazard value is divided by the exposure value, and the closer the quotient is to 1, the more likely there will be an unacceptable risk. Quotients less than 1 are considered acceptable, depending on the certainty in the components (hazard and exposure) of the risk assessment. Although this method has served well in conducting what may be called a "comparative" risk assessment (*comparing*, here meaning the risk of one chemical or stressor compared to another), it is not a useful method in assessing what many refer to as an "absolute" or receptor-based risk assessment. Thus, new methods are needed to assess risk from multiple stressors; assess risk across multiple-scales; link sources, stressors, and effects in terrestrial and aquatic systems; and integrate human and ecological risks. The ability to assess risks from global climate change, forest decline, reproductive failure and decline in species, and loss of biodiversity and habitat require the development of new assessment methods. In particular, these methods must help to understand how multiple stressors effect the vulnerability and sustainability of ecological resources within the context of multiple endpoints at multiple scales.

3.4.4.2 Specific Focus

Although there is much to be done in methods research, the following areas are considered to be the most important and of highest priority for ORD.

3.4.4.2.1 Place-Based Methods

Research is needed into how to conduct a place-based risk assessment. Terms like hazard, exposure, receptors, and vulnerability have different meanings when conducting a place-based risk assessment. One of the most important concepts to understand is how to derive a "landscape-stressor" response curve, essential for making a risk management decision. For example, how would the x and y parameters be derived in a stress-response curve when the stressor is an invasive species and the response is habitat alteration? The complex relationships of landscapes, ecological receptors, and condition and how these are considered in a place-based risk assessment demands that emphasis be placed on place-based assessment methods.

3.4.4.2.2 Indicators and Assessment Endpoints

The development of ecological indicators is a major research priority of this strategy. Determination of which indicators should be selected and used to measure ecological condition must be guided and directed by the risk assessment process. The choice of indicators is driven by societal values and the management goals that are articulated for protecting and restoring ecosystems. It would be tragic to develop indicators of ecologic condition that have no relationship to assessment endpoints. Thus, indicator development and risk assessment methods will be coordinated, and the research will be conducted in a highly cooperative manner across all of ORD's ecological research units.

One of the areas that will be emphasized is the societal value of ecosystems and how value impacts indicators and risk assessments. Indicator development and risk assessment methods will have to take these factors into account, and the research in both areas will include the collection and synthesis of ecological values from a variety of stakeholders, using sociological measurement methods. What to protect, at what level to protect it, and the measure of success in protecting the resource are critical components of this research strategy. Initial work already has begun through a joint NSF/EPA solicitation in ecological values. The early results of research show how ecological values are identified and incorporated into measurements and assessment endpoints. Much of the research will be carried out in those places where work is already underway, the five watershed case studies, the Mid-Atlantic area, and Region X.

3.4.4.2.3 Extrapolation

The issue of extrapolation continues to be an important one in the field of ecological sciences. There is a pressing need to extrapolate, from single species to populations, communities, and ecosystems; from surrogate test species to the untested species; from known or studied places to unstudied places; and from simple systems to more complex systems. Most approach the issue of ecosystem stress by choosing a simple system, studying it, and applying the results to a more complex system. This is the standard "reductionist" approach to complex systems and has served well to better understand many of the components of ecosystems and how they function. There is a need, however, to understand how the whole system works by taking a more systems or holistic approach and then extrapolating by applying the results to whole ecosystems.

There remains a substantial amount of research to be done to assess multiple stressors, multiple endpoints, and multiple scales and to be able to extrapolate the results to other places. Risk assessments like the MAIA are designed to assess the risks to that area, as well as advancing the science of risk assessment. The term *integrated assessment* refers to integration across resources (e.g., aquatic versus terrestrial), scale (e.g., national versus regional) and sector (e.g., "natural" processes versus human-induced impacts). Many agencies at all levels of government, as well as other organizations, are attempting to generate assessments, but without improved methods standardization, organized hierarchical approaches, and the development of "objective-values-endpoints-measures" paradigms, these often end up being little more than interpretive reports. A major research need is to focus on the development of multiple spatial scales (watershed and larger) ecological assessments methods that can be extrapolated and applied to many different types of ecological systems.

3.4.4.2.4 Integration of Human Health and Ecological Risk

Over 40 years ago, dead and dying cats and birds provided an early warning of mercury-contaminated fish that subsequently resulted in widespread human health effects in Minimata, Japan. Soon thereafter, Rachel Carson's *Silent Spring* (1962) again demonstrated the significance of wildlife as indicators of environmental contamination. Today, there are new examples of animals serving as sentinels of potential environmental health effects. Environmental endocrine disruptor effects observed in wildlife offer valuable insight into potential human health effects, and other environmental issues, such as the increased occurrence of deformed frogs in the Midwest, continually are being identified. Research will be conducted to build on the frequently underutilized commonalities between human health and ecological risk assessment and to develop, validate, and test new approaches for using animals as environmental sentinels for problems with potential human health consequences.

The sentinel species research will encourage the development and use of a broader range of available information to address critical human health and ecological issues. The initiative will focus on the development, validation, and use of sentinel species approaches to improve human health and ecological risk assessments. A range of techniques will be evaluated, including further use of disease information from companion and food animals, effects data from ecoepidemiologic surveys of aquatic animals and wildlife, and the use of in situ monitoring and assessment methodologies. Correlative relationships between occurrences of human and animal environmental diseases will be evaluated. The interpretation and appropriate use of these data in risk assessment will be emphasized.

3.4.5 Implementation

Most of the work done under this research area will be done as an in-house effort utilizing interdisciplinary teams. The teams will be chaired by a risk assessor from NCEA and will be comprised of staff from the other labs as appropriate. The team for MAIA also will include staff from the regional office as well as staff from other federal agencies. The size and composition of risk assessment teams will be determined by the scope of the risk assessment. Small-scale assessments may be done by a small team of staff within NCEA, whereas large-scale assessments, such as the one in the Mid-Atlantic region, will involve many staff with appropriate expertise and knowledge. Information from the STAR program will be factored into these assessments by conducting annual review meetings with grantees who are working on projects that can contribute to risk assessments.

ORD plans to conduct an annual ecological risk assessment symposium to advance the state of science, to share the results with the EPA program offices, and to help plan for future risk assessments.

3.4.6 Government Performance and Results Act Milestones

- **By 2001**, complete an assessment estimating the relative vulnerability of forests and small streams in the Mid-Atlantic region of the United States to multiple stressors, including habitat change, acid deposition, acid mine drainage, global change, ozone, pesticides, and nitrification.
- **By 2002**, issue guidance on methods to conduct place-based risk assessments.
- **By 2005**, prepare a synthesis report on conducting ecological risk assessments at watersheds, and indicate how these results can be applied to watershed-scale risk assessments.
- **By 2005**, make ecotoxicology data available on 600 chemicals through IRIS.

3.5 Ecosystem Risk Management and Restoration

Government Performance and Results Act Subobjective:
Develop prevention, management, adaption, and remediation technologies to manage, restore, or rehabilitate ecosystems to achieve local, regional, and national goals

3.5.1 Background

Ecosystem management and sustainability recently have moved to the forefront of both scientific and policy debates (Christensen et al., 1996; Baker, 1996; Morrissey, 1996). Many of the issues raised remain unresolved (including consensus on the meaning of sustainable ecosystems), but one thing seems clear: the increasing attention to ecosystem management, in tandem with discussions of sustainability, represents a significant reexamination of U.S. land and natural resources management practice and policy (Haeuber and Franklin, 1996). Risk management actions are an important part of ecosystem management and typically occur at multiple scales. For example, transboundary issues such as acid deposition and atmospheric levels of greenhouse gases require risk reduction via widespread actions that usually are applied at every source. In most cases, active management- and technology-based risk management (which often follows as an implementation requirement from policies and regulations) typically is applied to watersheds or ecosystems that can be defined by watersheds. Accordingly, the strategic choices for the scales of risk management research are (1) "national", for regulatory based transboundary considerations, and (2) "the watershed", for most regulatory and local management efforts. The current set of EPA regulatory, oversight, and policy instruments for risk management include chemical-specific regulation via registration, control, and classification processes (FIFRA) as amended; discharge and use permits that require compliance with ecologically based criteria (CWA and CAA); technology-based requirements for specific pollutant sources and constituents (point and non-point sources [CWA, Coastal Zone Management Act [CZMA], and CAA]); policy initiatives often in concert with other international, federal, or state agencies (Montreal Protocol, Climate Convention); review and approval of environmental impact statements for federally funded projects (NEPA); and site remediation as part of mandated clean-up programs (SARA, RCRA).

Significant focus will be given to Community Based Environmental Protection and watershed planning for flexible local implementation of selected regulatory requirements, as well as for reaching local environmental goals that can be above the regulatory floor. These local, collaborative planning efforts often attempt to integrate community values for economic, social, and environmental concerns to reach locally defined sustainability goals and offer new research opportunities.

Technological and policy-based risk management options are now available. However, given the rate of development of the man-made environment, present regulatory approaches may not always limit risks to tolerable levels for vulnerable ecosystems. There is a need to develop new, cost-effective prevention, control, and remediation approaches for sources of stressors and adaptation and restoration approaches for ecosystems. Risk management options, from pollution prevention through ecosystem restoration, correlate in sequence with the steps of the Ecological Risk Assessment Paradigm in the sense that some options can eliminate stressors at their source, and some can manage stressors to acceptable levels, whereas others adapt to unavoidable stressors and repair damaged ecosystems to functioning levels. Ultimately, the risk management research products must be fully integrated with risk assessment research products and support decision-making needs of risk managers in meeting regulatory or community-based goals.

3.5.2 Ecosystem Risk Management

Develop prevention, management, adaptation, and remediation technologies to manage or reduce stressors in watersheds

3.5.2.1 Background

A number of issues have been identified that provide the rationale for ORD risk management research, the highest priority of which are

- land use changes and pollutant loadings from urban and infrastructure development needs, agriculture, and other economic development increasingly are responsible for ecosystem degradation and loss of ecosystem function;
- non-point sources of pollutants (including atmospheric sources) remain the largest uncontrolled pollutant problems in watershed and aquatic ecosystems;
- contaminated sediments are a priority remediation challenge for coastal and freshwater ecosystems; and
- local communities do not yet have the data, tools, and demonstrated technologies to design and implement successful risk management programs for ecosystems.

The science and engineering needs for stressor source characterization, prevention, reduction, and other management alternatives to address these priorities include

- developing and applying stressor source characterization methodologies, such as Environmental Life Cycle Assessment;

- developing the pollution prevention approaches, source control technologies, remediation practices, and watershed planning methods to manage or reduce stressors to levels that protect ecosystems and meet public health goals;
- identifying criteria for the optimum mix of risk management policies, technologies, and approaches within watersheds, based on effectiveness and economics; and
- developing watershed management decision support systems to assist local planners in evaluating options in the complex integrated airshed/watershed/groundwater context and transferring the information to the user community.

Three areas will be the focus of ecosystem management research: (1) pollution prevention, (2) control technology, and (3) remediation.

3.5.2.2 Pollution Prevention

Develop and verify improved tools, methodologies, and technologies to improve or maintain ecosystem condition at watershed scales

3.5.2.2.1 Rationale and Objectives

Pollution prevention (P2) has been applied primarily as a way for industries to reduce costs to meet national effluent and emission standards and is still being developed as a means to further reduce ecologically important emissions (e.g., chlorofluorocarbon [CFC] and solvent substitutions). A broader application of P2 in a watershed context offers promise as a part of achieving sustainable communities, including ecosystems. As development within watersheds proceeds, particularly in those urban fringe areas susceptible to sprawl, community planners are asking long-term questions regarding how housing, commercial buildings, roads, and other infrastructure elements can be designed and operated to minimize resource consumption and the pollutants that affect nearby ecosystems. For example, Environmental Life Cycle Analysis is a well-developed analytical tool to enable systematic examination of the tendencies for a given design of a process, system, structure, or product to consume resources and to generate pollutants. Using such a tool, in combination with risk assessment information, it is possible to characterize sources of stressors and identify designs that minimize their occurrence. Research objectives within this area will focus on examining the most beneficial pollution prevention approaches for remaining major industrial problems and identifying the most cost-effective applications for pollution prevention within a watershed context.

3.5.2.2.2 Specific Research Foci

ORD Research in the ecologically related pollution prevention area will be directed to these objectives.

- Develop stressor source characterization approaches based on Environmental Life Cycle Analysis and related approaches. Life cycle analysis and other P2 tools developed for industrial applications will be evaluated and modified as appropriate for application to watershed and ecosystem management.
- Identify chemical substitutions and other pollution prevention solutions that are most cost-effective for alternative CFC substitutes, solvents, tropospheric ozone precursors, and pesticides. Opportunities to reduce major and widespread stressors that present exposures to ecosystems over large areas and that contribute to transboundary problems will be exploited. Criteria for reducing the highest risks to ecosystems will be applied to research projects traditionally focused exclusively on the industrial sector.
- Identify criteria for the most cost-effective applications of pollution prevention for design of new development in a watershed context. Cost accounting approaches, valuation research from the grants program, and the integration of P2 and business cycles will be exploited for application to watershed and ecosystem management.

3.5.2.2.3 Control Technologies

Develop best management technologies to reduce the impact of watershed development on the biological and chemical condition of stream quality

Rationale and Objectives

Ecosystem research is often characterized as "place-based" because the stressors, their impacts, and their reduction and management are most often ecosystem specific and can only be understood and reduced "in-place". Notable exceptions to this characterization exist; among these are control technologies that reduce emissions to the atmosphere or to aquatic systems that are applied to all sources.

Watershed management has evolved during the past two decades to depend heavily on defining and implementing BMPs that are directed primarily at non-point source problems, including wet weather flows. BMPs are designed to minimize the ecosystem (and human health) impacts of the watershed activity, while permitting their continuation. Examples are erosion controls for urban development, nutrient and pesticide management for agriculture, and storm water management in urban watersheds. BMPs are not new and, although uncertainties remain about their cost-effectiveness, a considerable body of research has been completed, and BMPs now are widely promoted by both watershed managers (federal, state, and local agencies; planning commissions; etc.) and land use managers (farmers, foresters, developers, miners, etc.) The ongoing research program in wet weather flow control technologies and related watershed planning issues is described in more detail in Section 4.

Specific Research Foci

Research in the control technology will be focused on

- defining, developing, and demonstrating the most cost-effective control technologies for reducing greenhouse gas emissions, wastes, and waste waters; pollutants in effluents and emissions; and BMPs for managing storm water runoff;
- identifying, developing, and demonstrating the most cost-effective combinations of pollution prevention approaches and control technologies for reducing stressors to major ecosystems in the United States; and
- defining, developing, and demonstrating cost-effective control approaches for emerging risks, including endocrine disruptors, cryptospiridium and other pathogens, and atmospheric deposition, and for multimedia effectiveness, including impacts on ground- and surface waters.

3.5.2.3 Remediation

Develop techniques to improve decontamination of stream sediments

3.5.2.3.1 Rationale and Objectives

Remediation of contaminated portions of watersheds is often desirable, if not necessary. Since 1980, almost all remediation research has been directed to waste site cleanup and has usually been driven by human health risk concerns. Increasingly, data are showing that contaminated sediments threaten ecosystems, and that waste sites having contaminated groundwater and soils pose threats to ecosystems. Although the actual ecological risks of contaminated media remain uncertain, EPA has clear mandates for action to clean up sites, and aggressive risk management steps are contemplated. Remediation approaches for contaminated media within ecosystems must be modified to focus on reducing stressors while sustaining ecosystem functions. Reducing specific chemical contaminants to risk-based toxicological levels may not be sufficient remediation if the technology used to reduce such levels introduces additional or unacceptable risks. For example, dredging contaminated sediments for high-energy treatment in engineered treatment systems is generally more costly and may be more ecologically disruptive than strategies for in situ bioremediation coupled with partial or complete containment. Similarly, phytoremediation (using plants to remediate soils and groundwater) applied in strategic locations in watersheds may be effective in passive cleanup of widespread contamination from pesticides and waste site residuals.

3.5.2.3.2 Specific Research Foci

Research in the remediation area will be limited primarily to

- defining the most applicable existing remediation technologies for contaminated media within vulnerable ecosystems;
- developing new, cost-effective technologies for in situ treatment of contaminated sediments;
- defining or developing remediation options for reduction of lower level, but still ecologically relevant, concentrations of spatially dispersed contamination, including pesticides in groundwater, plumes from waste sites, and contaminated sediments; and
- defining conditions where ecosystem restoration approaches (described below) increase the resilience of ecosystems to levels that reduce requirements for remediation of contaminated media.

3.5.2.4 Implementation

The work described here will be completed largely by NRMRL, with contributions from grants issued by NCERQA. Remediation research will be coordinated with efforts in NERL and NHEERL on the development of sediment quality criteria, indicators for exposure and effects, and opportunities for place-based field research (e.g., the MAIA will be exploited for joint implementation of field work).

3.5.2.5 Government Performance and Results Act Milestones

- **By 2000**, identify and test one chemical replacement for existing CFC substitutes having high global warming potential.
- **By 2002**, develop global change adaptation strategies and costs for pollution control, water supply, and related infrastructure.
- **By 2005**, demonstrate at least two reliable and cost-effective in situ technologies for the treatment or containment of in-place contaminated sediments.
- **By 2003**, complete an assessment of the requirements and costs of mitigating and adapting to the watershed vulnerabilities identified in the Mid-Atlantic regional vulnerability assessment.
- **By 2008**, demonstrate cost-effective adaptation and mitigation technologies for watershed and regional systems in at least two regions of the United States, including the Mid-Atlantic region.

3.5.3 Adaptation

Develop techniques to restore or rehabilitate ecosystems to achieve local, regional, and national goals

3.5.3.1 Background

Adaptation activities are efforts enabling improved accommodation to inevitable stressors, exposures, and habitat alteration. Climate change impacts, for example, and the residual and cumulative impacts from other multiple stressors likely will require adaptation and restoration measures to sustain ecosystems for future generations. Adaptation is closely linked to ecosystem restoration, described in more detail below. Rehabilitating an ecosystem may decrease significantly its vulnerability to stressors. For example, restoring riparian zones within watersheds is an adaptation measure that may be applicable for certain land use activities within the watershed that cannot be excluded for economic or political reasons. Adaptation includes intentional introduction of nonnative species or biotechnological modifications of species to alter vulnerabilities and carries with it notable risks.

3.5.3.2 Adaptation

Develop techniques to decrease the risk of degradation through adaptation of the landscape, ecosystems, and species

3.5.3.2.1 Rationale and Objectives

Ecosystem stressors from both natural and anthropogenic sources are inevitable, and cost-effective stressor reduction, as a means to reduce risks, may not always be feasible or practical. Granted, investments in stressor reduction are quite large, and innovative technologies could emerge for virtually every circumstance. Investments made now in developing adaptation approaches for ecosystems that make them more resilient to inevitable stressors are directed toward sustaining ecosystems into the future.

Adaptation is not simply a means to enhance the assimilative capacity of ecosystems so that they can tolerate increases in stressors, including pollutant loads and land use changes. Rather adaptation is a means to enhance the sustainability of ecosystems after stressor reductions and pollution prevention have reached their maximum achievable levels.

3.5.3.2.2 Specific Research Foci

Research in the adaptation area will focus on

- defining, developing, and evaluating adaptation options for climate change and other transboundary stressors, including the costs and effectiveness of these options;
- developing adaptation approaches to accommodate ecosystems to inevitable stressors;
- identifying circumstances where adaptation measures are less costly and produce lower ecological risks than does remediation of contaminated ecosystem media; and
- evaluating the practicality of effective eradication of undesirable nonindigenous species and prevention of their future invasion, including cost-effective approaches for the most serious terrestrial and aquatic problems.

3.5.3.3 Habitat Modification and Restoration

Government Performance and Results Act Objective:
Restore and protect watersheds

3.5.3.3.1 Rationale and Objectives

Increasingly, ecologists are noting that loss of habitat and degradation of ecosystems are derived from land management practices, intensive watershed development, hydrologic modifications, erosion and sedimentation, and human infrastructure "build out". This increased recognition also is emerging in risk-based, watershed assessments. Related stressors are multiple, and impacts are both direct (e.g., loss of wetlands and riparian zones to construction and development) and indirect (e.g., nutrient enrichment and herbicide impacts on field-edge vegetation and related impacts on fauna).

Changes in landscape composition and pattern can influence significantly the fundamental ecological processes of water, nutrient and materials, energy, and biotic flows and fluxes at a variety of scales, which, in turn, affect the risk to and sustainability of desired conditions in valued ecological goods (e.g., high-quality and abundant water, productive forests, and abundant and diverse wildlife) and services (e.g., watershed resistance to flooding). It is through the modification of these patterns (e.g., increasing forest fragmentation, roads crossing streams, and agricultural on steep slopes) that humans threaten sustainability of ecological goods and services that permit local and regional socioeconomic stability and resilience.

EPA's mandates for assessing ecological risks from this array of activities and for mitigating their impacts through restoration programs are both long-standing and emerging. The CWA requires wetland mitigation as part of the joint EPA/Corps of Engineers (COE) implementation programs. Non-point source control programs, as part of the CWA and the CZMA, require EPA to identify problems, provide solutions, and promulgate programs and regulations. NEPA requires environmental impact assessments for certain federal projects. More recently, litigation centered around the TMDL process apparently will lead to incorporating ecosystem restoration and habitat modification limitations into water quality management at the watershed scale.

In any case, the relative risks posed by the full array of stressors, in combination with calls for risk management options for sustaining ecosystems for coming generations, signal the need for an active research program. Risk management considerations will be engaged at local and national scales and will address both improvements to restoration approaches and the technical foundation for restoration policies developed by others.

3.5.3.3.2 Specific Research Foci

All elements of the ecological risk assessment process must be involved to evaluate damaged ecosystems and to provide the ecological basis for managing the risks and restoring the ecosystems. Although chemical-pollutant-based risk assessments enjoy a relatively long history of both research and application within EPA, habitat modification and restoration are emerging as important issues, both scientifically and operationally.

Specifically, research will focus on the need to develop (1) protocols and indicators to diagnose ecosystem restoration needs; (2) criteria to evaluate progress toward restoration; (3) analysis of technical issues related to riparian zone policies; (4) data for costs and effectiveness for watershed ecosystem restoration practices; and (5) decision support systems for state and community planners and their supporting consultants to establish ecologically relevant goals and facilitate consistent, cost-effective decisions on ecosystem restoration within watersheds.

Landscape Characterization

In many cases, habitat and landscape alterations pose far larger threats to the integrity and sustainability of our ecosystems than do pollutants. Landscape characterization documents the composition and spatial relationships (patterns) of ecological resources, including forests, streams, estuaries, urban environments, and agricultural and rangelands, over a range of scales, as it relates to ecological condition and resource sustainability. Spatial patterns of other biophysical attributes, including geology, climate, topography, hydrology, and soils, often influence (or determine) landscape composition and pattern and the sensitivity of ecological resources to stressors within any given area. Therefore, characterization of landscape composition and pattern is fundamentally important in understanding the relative vulnerability of and the risks to ecological goods and services valued by society.

Additionally, an understanding of the relationships between landscape composition and pattern and conditions of ecological goods and services can lead to formulation of a set of alternatives to reduce vulnerability and risk. Development of methodologies and tools to characterize landscapes should reduce significantly the uncertainty in vulnerability and risk assessments and in formulation and implementation of risk reduction strategies at a variety of scales.

Eco-criteria for Habitat Modification and Restoration

Protecting aquatic ecosystems requires moving beyond a dependency on traditional chemical-specific criteria and whole-effluent testing. Additional stressors, such as habitat modifications, increased sediment loads from erosion, and overenrichment of nutrients, often are cited as causes of ecosystem degradation. EPA is moving toward a more comprehensive watershed approach to ecosystem protection to accommodate these and other human-induced stressors. Methods to establish biological criteria, to assess the cumulative impacts of human activities in a watershed, and to diagnose causes of degradation are needed.

The development of criteria to protect and sustain ecosystem resources also depends on research to better understand how populations, communities and ecosystems operate and how they respond to stressors introduced by human activities. Sustainability also depends not only on the integrity of individual ecosystems, but also on the exchange of materials and energy within and among ecosystems within a watershed or region.

Riparian Zones

The Office of Water, the regions, and the federal natural resource management agencies have placed considerable emphasis in the last 1 to 2 years on the concept of stream corridor and riparian zone management and restoration. Research has demonstrated that riparian zones can be effective in reducing pollutant loads to streams, and stream corridor management and restoration is known to increase the quality of stream habitat for fish and other aquatic species. A leading question for future ecosystem restoration policy development is the extent to which many watershed restoration goals can be met by focussing on stream corridors and riparian zones.

Watershed Restoration

The developing fringe upstream of Metropolitan Statistical Areas (MSAs) and coastal and estuarine areas have been under stress for some time, and, increasingly, communities are engaged actively in watershed management. These areas support over 60% of the U.S. population, and roughly one-half of its population increase during the last three decades has occurred in coastal and estuarine areas. These watersheds, in contrast to nationally recognized ecosystems (e.g., the Florida Everglades), are not heavily funded "research and application test beds" that have both research and operational budgets. Rather, such watershed restoration programs typically are organized as part of community-based initiatives.

These watersheds include areas that extend upstream of new development into agricultural and forested areas. In many cases, wetlands have been lost or degraded, riparian zones have been neglected or overdeveloped, soil has eroded severely, and, as a result, habitats are impaired by reductions in species diversity. In other cases, stream flow rates have been altered to the detriment of aquatic species. Tools, databases, and decision support systems are needed urgently by local planners and risk managers for these situations.

The Office of Water is actively promoting watershed restoration in these circumstances and most recently, President Clinton announced the American Heritage Rivers initiative that targets rivers to focus restoration and protection efforts. Although numerous advocacy programs have been launched, systematically collected data to identify the cost-effectiveness of such efforts are sparse, and large uncertainties exist about the long-term success of restoration projects.

Decision Support for Risk Managers

Ecosystem restoration within watershed settings will become increasingly important in protecting and sustaining ecosystems as communities and watershed management organizations employ such restoration methods. The most common needs for decision information will be those of local groups committed to restoration and those of regional and state programs that promote restoration as part of total water quality management programs. The Office of Water anticipates that the waste load allocation process, which uses TMDLs as a means to allocate obligations for improvement in water quality, will increase dramatically the demand for restoration practices. Thus, restoration goals and opportunities must be considered in both water quality and ecological contexts. Central to this implementation framework is the need to provide decision-support systems for efficient and systematic planning and implementation.

The form and content of decision-support systems not only will build on the specific restoration technologies under development within ORD, but also will consolidate and integrate data, case studies, and information produced by others, including the ORD STAR program. Where appropriate, remotely sensed data, diagnostic indicators, and EMAP results will be combined to provide relevant decision support for watershed managers.

3.5.3.4 Implementation

All laboratories and centers will have active projects directed to solve this problem. Intramural projects will include indicator development and ecocriteria, landscape characterization and analysis for urban watersheds, and restoration technology development. Watershed ecological risk assessment case studies will be conducted to strengthen assessment methods and to support continued development and refinement of the Ecological Risk Assessment Guidelines.

Extramural research will include development of watershed and ecological process models that explicitly consider landscape composition and pattern; development of socioeconomic models that project or predict the spatial distribution and magnitude of landscape change, given changes in human populations, economies, and social values; development of landscape indicators that treat scale as a variable; and watershed planning and management approaches for restoration in urban systems.

3.5.3.5 Government Performance and Results Act Milestones

All of the milestones in this area will be provided through the core program. However, the information is included here as well because of its direct applicability to the CWA.

- **By 1999**, make publicly available, land cover data for a baseline period (1990 to 1993) for all regions from which changes in land cover can be documented accurately and quantitatively.
- **By 2000**, report on the distribution of major stressors and exposures in the Mid-Atlantic region of the United States, including ozone, acid deposition, acid mine drainage, UV-B, nitrogen, sedimentation, pesticides, and others.
- **By 2000**, report on the condition and distribution of major receptors in the Mid-Atlantic region of the United States, including small streams, estuaries, forests, and others.
- **By 2001**, complete the first regional, comparative assessment estimating the relative vulnerability of forests, small streams, and watersheds in the Mid-Atlantic region of the United States to multiple stressors.
- **By 2002**, provide indicators of habitat suitability, landscape-level biotic processes, water resources, hydrologic processes, and terrestrial productivity for measuring the vulnerability of multiscale landscapes to change from multiple stressors; issue guidance on the conduct of place-based, multiscale, ecological risk assessments; provide cost-effective approaches for restoring riparian zones in the Mid-Atlantic region.
- **By 2003**, complete an assessment of the requirements and costs of mitigating and adapting to the watershed vulnerabilities identified in the Mid-Atlantic regional vulnerability assessment.
- **By 2004**, provide diagnostic tools and models for assessing feasibility, priorities, and measures of success for watershed restoration projects and issue guidance on the application of the tools and models.
- **By 2005**, complete an assessment of the regional sustainability/vulnerability of ecosystems in the Southeastern United States; provide decision support tools for watershed restoration projects.
- **By 2008**, complete an assessment of the regional sustainability/vulnerability of ecosystems to local, regional, and national stressors, now and in the future; demonstrate cost-effective adaptation and mitigation technologies for watershed and regional systems in the Mid-Atlantic region of the United States and in one additional region.
- **By 2008**, complete three pilot restoration projects for developed and partially developed watersheds with different endpoints of societal value.

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SECTION 4

High-Priority Research on Current Environmental Threats

Using core capabilities to address high-priority client needs

4.1 Introduction

The previous section provided the foundation and direction for the core research in monitoring, modeling, assessment, management, and restoration within ORD. These core capabilities are used to address high-priority client needs.

As described in the ORD Strategy, there is a process by which the highest priority projects for the application of the core capabilities are determined. The following sections describe those priority research areas and the objectives of that research. Within each problem area, GPRA goals or objectives/subobjectives (see Sections 1 and 2) are included as boundaries for the research activities.

ORD's research budget is structured in relation to the client offices it serves (Air, Water, Pesticides and Toxics, Hazardous Waste, and Multimedia—this last area being the source of most of the funding supporting the core research program). Therefore, this section of the strategy is divided by these budget categories and the highest priority environmental threats within those categories where ORD can make a significant difference by conducting the research.

4.2 Air Research

4.2.1 Background

None of EPA's air research goals have ecological resources as the primary endpoint of concern. Although there is interest in the exposure and effects of a variety of air pollutants on ecosystems, the primary focus is and has always been human health. The Ecological Research Program benefits from the human health goals because the modeling technology, in particular, is of importance as a means to forecast both current and future, large-scale exposures to ecosystems.

Several areas of research have, however, been chosen as high-priority issues for investment. One of those is ozone. Adverse effects have been documented for single species of vegetation and are likely to have influence on ecosystems as a whole. Ozone damage to plants is projected to be extensive, with an estimated impact exceeding $1 billion in lost food crops and timber products every year. Understanding atmospheric ozone formation, model development, and ozone effects research is therefore of the highest priority.

A second area of documented ecological risk is the deposition of acidic and acidifying substances. Clearly, both terrestrial and aquatic effects have been documented globally. ORD's role recently in this area has been the documentation of reductions in sulfur and nitrogen, wet and dry deposition monitoring, and lake and stream monitoring in sensitive areas. Future work in this area will continue documentation of changes in aquatic systems, as a result of changes in deposition; analyses of data to document these trends; and work in the core program on improving the understanding of wet deposition processes. In addition, increased effort will be placed on understanding anthropogenic nitrogen influences from sources that include air; the description of that work is found in the multimedia component of this section. Again, as with ozone, the core program and related modeling work is applicable in this area as well.

Other air-related issues that will receive attention in the research program are UV-B and global change. Both of these also are covered in the multimedia component of this section.

4.2.2 Specific Research Foci
4.2.2.1 Tropospheric Ozone

Government Performance and Results Act Subobjective:
Develop tropospheric ozone precursor measurements, modeling, source emissions, and control information to guide cost-effective risk management options and produce health and ecological effects information for National Ambient Air Quality Standards related to ozone risk assessments

4.2.2.1.1 Statement of the Problem

Chronic ozone exposures have been shown to cause significant forest and crop damage in North America. As a "criteria" pollutant, the CAA of 1970, and all subsequent amendments, have provided for NAAQS for ozone and sanctions against states failing to meet the prescribed NAAQS targets. Although considerable progress has been made since the 1970s in reducing the highest ambient levels of urban ozone exposures through national and local precursor emissions controls, there are still 106 counties not meeting the current NAAQS for ozone. The perceived failure of the current program to achieve greater health and ecosystem protection has led to continued interest and attention to the problem.

What makes the tropospheric ozone problem particularly difficult is that ozone is not directly emitted into the atmosphere, but rather is chemically formed in the air through the interactions of hundreds of reactions of other emitted pollutants, chiefly NO, NO_2, CO, and scores of VOCs. Optimal strategies for reducing ozone concentrations may shift among these precursor emissions as a function of space and time. In some cases, reducing the NO_X emissions (NO and NO_2) may actually lead to an increase in ozone, through the nonlinear chemistry involved in its formation. In the 1970s and early 1980s, the prevailing thinking was that ozone was chiefly a local pollutant, amenable to reduction by local (VOC) emissions control measures. Since that time, measurement and monitoring programs have demonstrated that ozone is a regional problem as well as an urban one, with ozone and its precursors being transported hundreds of miles, leading to interstate and international pollution problems. The ubiquity and reactivity of natural (biogenic) VOC emissions throughout eastern North America and the importance of NO_X emissions on the regionalization of the ozone problem have led to new thinking and proposed strategies for the control of ozone.

4.2.2.1.2 Critical Questions for ORD Research

Ozone Exposure Research

For over 25 years, many air quality research and management groups throughout the United States, Canada, and Mexico have struggled with the most significant implementation issues. Some of the most pressing questions are

- How does ozone accumulation on urban (<200-km) and regional (200- to 2,000-km) scales depend on the precursor source strength and location? How does it depend on the relative contribution from urban and regional sources?
- What do recent assessments indicate about the relative contribution of NO_X, VOCs, and CO to ozone accumulation on urban and regional scales in North America?
- For a given area, what portion of the ozone problem is local and what portion is transported into the area? What portion of the problem is essentially irreducible (natural sources) and what portion is potentially controllable?
- What are the strengths and limitations of the current scientific methods and tools in assessing tropospheric ozone issues and developing emissions management strategies?
- What approaches are required to determine historic concentration trends of ozone and its precursors on urban and regional scales? What is required to demonstrate the effectiveness of emissions control strategies over time?

- What are the relationships between the control strategies designed to manage tropospheric ozone and those designed to manage other pollutant regimes of concern?

NRC addressed many of these issues in their 1991 publication *Rethinking the Ozone Problem in Urban and Regional Air Pollution*. One of their major conclusions was that scientific progress had been hampered by the lack of a coordinated national strategy to address the issues in a systematic manner. Heeding the advice of NRC, EPA/ORD, along with NOAA and the Electric Power Research Institute, initiated discussions among most of the sponsors and participants in tropospheric ozone research in North America. The continental research program known as NARSTO officially was launched in 1995, with a charter signed by over 70 members of the public, private, and academic research communities, a comprehensive 10-year research strategy, and an organizational structure. There are four technical teams within NARSTO, and their principal research areas are indicated below.

(1) Modeling and Chemistry Team
  - Gas phase and aqueous atmospheric photochemistry and the development and evaluation of chemical kinetic mechanisms
  - Development and evaluation of meteorological analysis models for characterization of historical periods of photochemical pollution
  - Development, evaluation, and application of air quality simulation models applicable to urban and regional scales

(2) Observations Team
  - Development and testing of new in situ and remote-sensing instrumental methods for the measurement of trace gas species and meteorological parameters relevant to tropospheric ozone
  - Refinement, maintenance, and training in field-deployable instrumental methods for monitoring networks for ozone, NO_X, and VOC species and meteorological parameters
  - Planning and execution of intensive field campaigns and subsequent data analysis for atmospheric processes research and model application

(3) Emissions Team
  - Determination of "real-world" emissions factors and fluxes of NO_X, CO, and VOCs from on-road and off-road mobile emissions sources
  - Development and refinement of natural (biogenic) emissions factors and fluxes of ozone precursors from various soils, trees, and crops
  - Development and evaluation of emissions and projection models for area, point, mobile, and biogenic sources

(4) Analysis and Assessment Team
  - Periodic evaluation of the state-of-science of tropospheric ozone
  - Synthesize the research results from the other NARSTO teams and present them to customer communities, including those of human/ecosystem effects, policy and air quality management, and emissions control technologies
  - Assess linkages between tropospheric ozone and other pollutant regimes, including fine particles, acid deposition, and global climate change

Ozone Effects Research

ORD has given highest priority to research on the functioning and response of plants and the vegetative component of terrestrial ecosystems. This addresses the greatest scientific uncertainty facing EPA today in assessing risks to terrestrial systems. There are many questions regarding terrestrial wildlife, but many of these are being addressed by other research, including that of the Department of Interior. Less attention traditionally has been given to environmental stress on vegetation. In the past, vegetation has been considered to be an easily regenerated and manipulated natural resource that was relatively insensitive to environmental stress. However, the understanding and concern for this basic component of the biosphere has changed. Emerging knowledge of long-distance transport of tropospheric ozone and the peristence of this large-scale regional air pollutant in remote natural areas, as well as occurrence in the major crop-producing areas of the United States, leads to concern over potentially widespread degradation of ecosystem processes and loss of biotic diversity in terrestrial vegetation.

Two scientific questions are of particular importance for EPA regarding ecological effects of tropospheric ozone. One is the role of the belowground system that supports vegetation, the rhizosphere. The second question deals with extrapolation of experiment results. Because plants vary so greatly in their responses to a multitude of environmental factors, it is very difficult to relate results from exposures in chambers to the field. The first critical step in this understanding is to extrapolate from chambers to whole trees.

Role of the Rhizosphere in the Ecological Response of Terrestrial Systems

Because the rhizosphere is the interface between the primary carbon processes (i.e., aboveground carbon acquisition) and primary nutrient and water processes (i.e., belowground nutrient and water acquisition), it is essential to understand how specific stressors will affect this interface. The hypothesis is that impacts to carbon or nutrient acquisition will impact rhizosphere processes, and that direct impacts to the rhizosphere also will impair carbon and nutrient acquisition. Consequently, the goal of the rhizosphere research is to determine the effects of atmospheric pollutants and global change components (e.g., CO_2, precipitation, temperature, etc.) on key processes in controlling the exchange of carbon and nitrogen between the root/soil and the plant canopy.

Research will address a number of key rhizosphere processes. For example, elevated CO_2 increases fine root growth and fine root life span. In contrast, elevated ozone decreases fine root growth and is hypothesized to decrease fine root size span as it decreases fine root carbohydrate levels. Elevated ozone also increases soil respiration, despite reduced belowground carbon translocation. Intensive sampling in terracosms and at field sites provides the data necessary to parameterize ecosystem models that are used to develop a predictive understanding of the multiple stress effects on carbon and nitrogen cycling in forest ecosystems

Extrapolation of Plant Response—from Chambers to Trees

Understanding the effects of air pollutants and global change on vegetation, as called for in various legislative mandates to EPA, including the CAA, has involved collection of experimental data at the level of the individual and populations. Frequently, the studies have involved single species and single pollutants, resulting in exposure-response functions characterizing the effects on biomass or reproduction (crop yield) at the individual or population level of that species. Experimental observations of effects at higher levels of biological hierarchy (i.e., community and ecosystem) or increasing biological complexity (species diversity, stand structure, and presence of trophic functional groups) are limited. Invariably, the data from one set of experiments is extrapolated to predict the species' response nationwide. This often includes extrapolating the response in natural environments with all the concomitant moisture, nutrient, and competitive stresses that may be in place across the spatial and temporal extent of the species in question, even though the data sets do not include these conditions. In addition, only a very small representation of species is ever studied, and, yet frequently, these data are used to represent all vegetation, crop, or forest tree species.

At ecosystem and landscape scales, even less information is available to predict changes with changing pollutant exposure scenarios or changing global climate. An approach is required to develop the necessary linkages to extrapolate experimental data taken at the individual level, often in artificial conditions, to suggest changes occurring in more complex native environments to individuals or populations. Equal attention is needed to understand changes at higher scales of biological organization and landscapes. A multifaceted, interactive research approach is necessary, including experimental and modeling components, with each informing the other. The objective of this research is to provide a scientifically sound understanding of error sources in extrapolating from individual responses to ecosystem responses and across geographic scales. Additionally, a mechanistic knowledge of the ecosystem processes is needed to predict the multiple environmental stressor. The research involves experimental, modeling, and field studies at a range of scales from the individual to the landscape.

4.2.2.1.3 Implementation

At the same time that the continental NARSTO program was forming, ORD initiated its own EPA/NARSTO component by linking together, through a central program manager, the noneffects portions of tropospheric ozone research being conducted in NERL and NRMRL labs. These portions include atmospheric chemistry, modeling, methods development and field studies, emissions, and control technologies. Working teams have been established in these laboratories, and the program manager works with team leaders for coordination of research planning and implementation. Key members of the Office of Air and Radiation (OAR) staff are included in program planning discussions to ensure the relevance of the research to program office needs.

The EPA/NARSTO program conducts applied research in the areas of chemical kinetic mechanism development, advanced meteorological and air quality modeling (the Models-3 system, including the CMAQ model); new mobile source emissions factor and model development (modal mobile source models); new biogenic source models (Biogenic Emissions Inventory System;, and innovative, cost-effective NO_X source emissions controls. Most research is conducted by in-house scientists assisted by on-site contractor support. Extramural research, through contracts and cooperative agreements, is mainly awarded for support of the goals of the continental NARSTO programs and assessments and the continuing SOS, a university-led consortium studying the physical and chemical aspects of ozone climatology in the southeastern United States. Complementary research projects in both fundamental and applied ozone research are awarded through the extramural grants program administered by EPA/NCERQA.

4.2.2.1.4 Government Performance and Results Act Milestones

Because the research in this area may be as applicable if not more so to human health research, the following milestones are a shared responsibility between the two programs.

- **By 1999**, provide state-of-science assessment of tropospheric ozone issues by the NARSTO, a public/private consortium including EPA/ORD and other public and private sector sponsors.
- **By 1999**, provide an enhanced understanding of processes (chemistry, meteorology, and precursor emissions) of the photochemical ozone problem for the Middle Tennessee region.
- **By 1999**, analysis of SOS data from the 1995 field program in the Nashville/Middle Tennessee region.
- **By 1999**, develop an efficient and accurate method for including complex chemical reaction mechanisms in photochemical pollution models like Models-3.
- **By 2000**, complete the new release of a model that will provide more exact estimates of the variety of VOCs emitted from biogenic (natural) sources.
- **By 2000**, analysis and interpretation of observation-based and emission-based models and modeling methods developed under the SOS research program.
- **By 2000**, report on laboratory simulations of ozone- and particulate matter-forming potentials of anthropogenic and biogenic emissions.
- **By 2000**, complete Phase II of the diagnostic evaluation of Models-3/CMAQ against comprehensive field study data sets (EMEFS, SOS-Nashville, NARSTO-NE).
- **By 2002**, complete the external review draft of the ozone air quality criteria document.
- **By 2003**, conduct model evaluation exercises with a newly revised version of Models-3/CMAQ. The evaluation will focus on urban- and local-scale pollution problems and the larger scale influences on those problems.
- **By 2003**, produce ecological effects information for NAAQS-related ozone risk assessments.

4.2.2.2 Acid Deposition Research

Government Performance and Results Act Subobjective:
Reduce ambient sulfates and total sulfur deposition by 20 to 40% and reduce ambient nitrates and total nitrogen deposition by 5 to 10%

4.2.2.2.1 Statement of the Problem

Acid deposition effects on lakes and streams have been well documented. As a result, the CAA Amendments of 1990 have required reductions in sulfur deposition. Recent evaluations of long-term sulfur and nitrogen air concentration and wet deposition trends appear to show that the above subobjective has been met for both sulfur and nitrogen. Concern continues, however, as to whether these reductions protect the most sensitive of aquatic and terrestrial resources. Therefore, the focus of this research will be on evaluations of existing and future monitoring data as a contribution to the multiagency Acid Precipitation Assessment Program, continued monitoring of select lakes and streams in sensitive areas of the Northeast and Mid-Atlantic, and research at EMAP index sites to better understand acidification and deacidification processes.

4.2.2.2.2 Critical Questions for ORD Research

- What are the current and future trends in sulfur and nitrogen air concentrations and wet and dry deposition?
- What statistical approaches are best for measuring trends?
- What is the optimal network design for monitoring long-term local and regional trends in deposition chemistry?
- How best is dry deposition measured and estimated over regional scales?
- What are the trends in the recovery of lakes and streams from effects of acidic deposition?
- What is the optimal monitoring network for measuring long-term local and regional trends in lake and stream acidification and deacidification?
- What are the critical processes affecting acidification in watersheds?

4.2.2.2.3 Implementation

The Office of Air and Radiation will maintain a deposition monitoring network that will be the foundation of the data for analysis. EMAP will continue monitoring a prechosen, representative set of lakes and streams that are appropriate for estimating the regional changes in acidification in surface waters in the Northeastern United States. All of the ORD research will be done in-house with cooperators primarily from other agencies (see also anthropogenic nitrogen research in a following section).

4.2.3.2.4 Government Performance and Results Act Milestones

- **By 1999**, report on the trends in deposition of sulfur and nitrogen in the eastern United States.
- **By 2000**, assess ecological improvements in surface water condition resulting from reduction of SO_2 emissions in the Adirondacks.

4.3 Water Research

4.3.1 Background

The CWA Amendments, Section 101(a), provide the goals of restoring and maintaining the chemical, physical, and biological integrity of the nation's waters. To meet these goals, EPA initially focused on chemical measurements in the water column and on point source discharges. The major limitations of this approach was the lack of information on non-point source contributions, the inability to measure chemical movements through the food chain, and the lack of information on nonchemical impacts (e.g., habitat modification). To begin to address these limitations, EPA is beginning to supplement chemical measurements in the water column with other chemical measures, such as information on sediment and fish tissue contamination. In addition, there is now a recognition that nonchemical stressors and sources need to be identified to help assist water resource managers make sound decisions. Finally, there has been a recognition that to meet the goals of the CWA (i.e., to restore and maintain specific water bodies) requires a more global and holistic view of the entire watershed and sources of contamination and stress—the foundation of the core research program (see Section 3).

To help address some of these emerging water issues, better ways to measure and model the impact of different global and local sources and stressors to aquatic ecosystems need to be developed. A key tool to develop better models and measures is the development of indicators of stressors and the ability to link these to sources (i.e., to provide source "signatures"). Improvements in stressor indicators, source signatures, and overall measurements and models of ecosystem conditions will assist EPA in the following areas: better documentation to support designated uses for specific water bodies, and how to maintain them; improved abilities to identify problem sources for specific water bodies, and how to correct them; better tools for monitoring compliance agreements with point source and non-point source discharges or other sources on adverse impacts on aquatic ecosystems; and finally, better information on the status and trends of ecosystem conditions to help evaluate the effectiveness of current management initiatives and to help set priorities for future actions.

4.3.2 Specific Research Foci

4.3.2.2 Eco-criteria and Contaminated Sediments

Government Performance and Results Act Subobjective:
Provide means to identify, assess, and manage aquatic stressors, including contaminated sediments

4.3.2.2.1 Statement of the Problem

Aquatic sediments represent the ultimate repository for many contaminants in surface waters. Sediment-associated contaminants not only serve as a source of toxicity to benthic organisms living in contact with these sediments, but also can reintroduce contaminants into the water column or aquatic food chain. Recently, an EPA report on the National Sediment Quality Survey (EPA, 1996) reported that 26% of the 21,000 sampling stations in watersheds across the United States were categorized for a higher probability of adverse effects to aquatic life and human health. Another 49% were considered to have an intermediate probability for effects. Although sediment contamination decreases with distance from near-shore sources, widespread, low-level contamination of deep water sediments of Puget Sound, for example, has been detected. Cancerous lesions and other effects have been observed in several bottom-dwelling fish species and approximately 1,200 state fish-consumption advisories have been issued.

According to the NRC's 1997 report entitled "Contaminated Sediments in Ports and Waterways—Cleanup Strategies and Technologies," an estimated 5 to 10% of all sediments dredged in the United States are considered contaminated, translating into 14 to 28 million cubic yards of sediment annually that must be managed. The NRC report identifies many current deficiencies in the cost-effective management of contaminated sediments ranging from the lack of comprehensive risk assessments to the lack of systematic performance data on engineered and in situ remediation technologies. Three general problems arise:

(1) determining the ecological risks from contaminated sediments;
(2) managing risks from contaminated sediments in aquatic ecosystems where the sediments need not be removed for navigational clearance; and
(3) managing risks from contaminated sediments removed from waterways for navigational purposes—the dredge spoil problem.

4.3.2.2.2 Critical Questions for ORD Research

Eco-criteria and Indicators

The Office of Water has promulgated sediment quality criteria as an extension of water quality criteria. Further development of such criteria and their site-specific application will require better understanding of the effects of contaminated sediments for both benthic communities and ecosystem level impacts. Research questions are as follows:

- How can the biological effects of exposure to contaminated sediments be measured in the laboratory and in the field, and what are the most cost-effective ways to use such measurements in site-specific risk assessments?
- How can the biological effects of exposure to sediment contaminants be predicted, and how are such predictions factored in risk assessment?
- In cases where biological effects are demonstrated, what are the causes of those effects, and how is that information best used to devise risk management approaches?

Exposure—Fate and Transport

Current sediment quality criteria are based on equilibrium partitioning of hydrophobic chemicals between the sediments and the interstitial water. Further development of criteria will require a more complete understanding of the interactions of pollutants and sediments. Similarly, the remediation of sediments and the feasibility of natural attenuation are elucidated by knowledge of the fate of contaminants and the transport characteristics of both the sediments and sorbed materials. Research questions are as follows:

- What is the appropriate equilibrium-partitioning model for polar organics, metals, and zwitter ions attached to sediments?
- What are the fate processes, rate constants, and degradation products for the array of chemicals found on contaminated sediments?
- How are contaminated sediments factored in the waste load allocation modeling process for TMDL?

Remediation Technologies for In-Place and Dredged Sediments

EPA is evaluating two stressor management approaches for contaminated sediments: (1) natural attenuation (intrinsic remediation) and (2) enhanced remediation. Enhanced remediation includes both in situ and ex situ techniques and employs various combinations of biological, physical, and chemical processes. Natural attenuation is an emerging remediation approach that, under some conditions, allows biotic and abiotic mechanisms to restore ecosystems naturally.

The attenuation mechanisms include anaerobic and aerobic biodegradation or biotransformation, phytoremediation, chemical oxidation and reduction, adsorption, humidification, sedimentation, dilution, and dispersion. These processes require time to reduce the environmental chemical concentrations and often are used with containment technologies. For selected widespread, low- to moderate-contaminant concentrations, natural attenuation may provide the only practical approach to affordable risk management.

Investigations usually separate contaminated sediment requiring treatment into two categories: (1) dredged sediment created during navigational waterway maintenance and (2) sediment requiring action because of the risks posed to human or ecosystem health. System constraints on each category determine the solution effectiveness. Some conditions favor in situ treatment, whereas dredged sediment, by definition, requires ex situ treatment. A major challenge for remediation is the need to develop risk management approaches that restore ecosystems to functioning levels, in addition to reducing chemical concentrations to criteria levels.

Questions under investigation include the following:

- Among existing remediation technologies, which ones are most applicable for contaminated media within vulnerable ecosystems?
- What are the most appropriate and cost-effective technologies for in situ and ex situ treatment of contaminated sediments?
- What sediment management systems are most cost-effective in reducing risks?
- Under what circumstances are adaptation measures (e.g., in-place containment and low energy in situ treatment) for contaminated sediments less costly and produce lower ecological risks than alternative remediation?

4.3.2.2.3 Implementation

The work described in this problem area will be accomplished through a combination of intramural and extramural research conducted in all ORD laboratories. Within the federal research community, NOAA and the U.S. Army Corps of Engineers (COE) also conduct research on selected issues. The 1997 NRC report, "Contaminated Sediments in Ports and Waterways—Cleanup Strategies and Technologies," contains recommendations for a more integrated federal research and development program. ORD intends to establish a more coordinated effort (and possibly a joint research strategy) with the COE to investigate the development and demonstration of innovative technologies for removing and managing contaminated sediments.

4.3.2.2.4 Government Performance and Results Act Milestones

- **By 1999**, develop methods for screening aquatic systems, including sediments, for significant chemical stressors.
- **By 2000**, improve the understanding of the kinetics of contaminant release from sediments.
- **By 2000**, provide a systematic framework for developing habitat criteria for aquatic systems.
- **By 2000**, develop methods and models to assess bioaccumulation of sediment contaminants.
- **By 2000**, quantify photo-activated toxicity of sediment-associated PAHs.
- **By 2000**, develop methods to validate and predict lab bioavailability data for sediment contaminants to the field.
- **By 2000**, develop methods and models to determine effects of spatial, temporal and other factors on toxicity of sediment contaminants.
- **By 2000**, develop methods and indicators to assist in setting aquatic ecocriteria.
- **By 2001**, develop risk estimates/criteria for specific contaminants or mixtures of contaminants protective of aquatic life and human health to develop risk assessments of human health and ecological risks for exposures to contaminants in ambient waters.
- **By 2001**, develop or evaluate promising technologies for the ex situ risk management of contaminated sediments.
- **By 2001**, develop methods to assess the success of remediating stream ecosystems, including stressed riparian zones and metal-contaminated sediments.
- **By 2002**, publication of research methods to develop diagnostic indicators for benthic ecosystems to identify sensitive indicators of toxicity to benthic communities.
- **By 2002**, document effects of sorption on biotic and abiotic transformation rates in sediments.
- **By 2003**, develop or evaluate promising technologies for the in situ risk management of contaminated sediments.
- **By 2003**, develop methods to assess reproductive effects of sediment contaminants.
- **By 2003**, develop methods and models to predict effects of highly bioaccumulative contaminants on wildlife and other higher trophic-level organisms.
- **By 2003**, determine effects of sediment contaminants at population, community, and ecosystem scales.

4.3.2.3 Wet Weather Flow

Government Performance and Results Act Subobjective:
Deliver decision support tools and alternative, less costly wet weather flow control technologies for use by local decision makers involved in community-based watershed management

4.3.2.3.1 Statement of the Problem

The urban wet weather flow (WWF) problem is caused by untreated discharges during storm events. Early drainage plans made no provisions to control impacts from this type of pollution. WWF comprises point source as well as diffuse non-point source discharges. There are three types of urban WWF discharges: (1) *combined sewer overflow (CSO)*, a mixture of storm drainage and municipal-industrial wastewater discharged from combined sewers or dry weather flow (DWF) discharged from combined sewers resulting from clogged interceptors, inadequate interceptor capacity, or malfunctioning CSO regulators; (2) *storm water* from separate storm water collection systems in areas that are either sewered or unsewered; and (3) *sanitary sewer overflow (SSO)*, overflow and bypasses from sanitary sewer systems resulting from storm water and groundwater infiltration or inflow.

Pollutants in WWF discharges from many sources remain largely uncontrolled. EPA, in both its 1992 National Water Quality Inventory (EPA, 1994a) and its 1995 Report to Congress (EPA, 1995a), cited pollution from WWF as the leading cause of water quality impairment. WWF from both point and non-point sources is one of the greatest remaining threats to water quality, aquatic life, and human health that exist today. The Office of Water, in its "National Water Program Agenda—1997-1998," identifies the management of WWF dischargers as one of the key areas remaining to assure clean water and safe drinking water. Furthermore, this agenda states that, "[p]ollution from diffuse or non-point sources during and after rainfalls is now the single largest cause of water pollution." These discharges can produce widespread, short-term, high exposures to infectious agents that result in gastrointestinal illness and even death. In addition, there is an increase in long-term contamination of sediments and the aquatic food chain through the release of persistent, bioaccumulative toxic agents. Urbanization also creates higher stream flows, causing bank and bottom erosion and deposition and unacceptably high shear stresses for the benthic community.

NRC (1992) concluded that correction of non-point source pollution problems is a major priority of surface water protection and should be implemented as a part of a large-scale, aquatic-ecosystem program. Pollution problems stemming from CSO, SSO, and storm water discharges are extensive throughout the United States, with the Northeast, Southeast, Midwest, and Far West being the principal areas of concentration. Almost 40% of rivers, lakes, and coastal waters monitored by states do not meet water quality goals, largely because of urban WWF discharges.

4.3.2.3.2 Critical Questions for ORD Research

WWF problems can be addressed in three fundamentally different ways: (1) watershed management (i.e., managing activities within the watershed in ways to minimize or prevent unacceptable ecological impacts); (2) control technology for drainage systems (i.e., using engineered control systems to treat or remove pollutants from WWFs); and (3) infrastructure improvement (i.e., developing new infrastructure systems that create fewer WWF problems, and applying such concepts to existing infrastructure as it is replaced, and incorporating new concepts into planned development). Each of these potential solutions poses critical ORD research questions.

Watershed Management for WWF Impacts Abatement

Solving WWF problems through watershed management is consistent with the Office of Water strategy on watersheds and involves a progression of research questions and steps:

- How can effluent guidelines for WWF be established effectively in a watershed management strategy?
- What are the methods and data needed to diagnose problems, identify and characterize sources (including atmospheric deposition), and evaluate progress toward success in watershed management?
- What innovative and less costly watershed management practices and WWF management networks need to be developed? Are riparian zone restoration and constructed wetlands most effective?
- What combination of best management practices, source controls, watershed restoration, and retrofitted technologies provide the most cost-effective strategy for improving water quality within the context of watershed management?

Control Technology for Drainage Systems

WWFs including storm water, are increasingly suspect, if not directly the cause, of pathogenic contamination of shellfish beds, public beaches, and drinking water supplies. In some cases, control technologies and preventive measures are effective in reducing the toxicity of CSOs and other WWFs. Research questions/directions are as follows:

- What is the effectiveness of disinfection techniques using measurements that account for microorganisms occluded by particles?
- Develop and demonstrate new, low-cost, high-rate control/treatment technologies for removing toxics and other pollutants from WWF and evaluate their effectiveness relative to meeting water quality goals.
- How can toxic/pollutant discharges to receiving waters of the urban watershed be prevented and reduced effectively?

Infrastructure Improvement

A 1990 report by the Congressional Office of Technology Assessment identified environmental infrastructure problems in the areas of wastewater, drinking water, and municipal solid waste and evaluated the impacts of these problems on local communities. As is apparent, a community's environmental infrastructure needs are varied and interrelated. Communities may have the same generic needs (providing safe drinking water, protecting receiving waters, environmentally acceptable disposal of solid waste, etc.) and associated problems; however, the solutions to these problems can vary greatly with community size because smaller communities can lack the financial (lower per-capita income, smaller tax base, etc.) and personnel resources (operation, maintenance, management, etc.) of larger ones, forcing the use of lower cost, less complex technologies. Questions are as follows:

- What are the best approaches to design, construct, maintain, and rehabilitate water distribution systems and to ensure water quality in urban settings?
- What are the best approaches to assess, maintain, and rehabilitate existing sewer systems and to construct new sewer systems in urban settings?
- What are the best approaches to assess, construct, operate, and maintain potable water storage and treatment systems to ensure optimum system performance and, thus, reduce the risks to public health and safety?
- What are the most cost-effective approaches to design, construct, maintain, and rehabilitate storage systems for storm water and wastewater to ensure optimum system performance and, thus, reduce the risks associated with the failure of such systems to the environment?

4.3.2.3.3 Implementation

The work described in this problem area will be accomplished exclusively by the ORD laboratories and centers. Implementation will be based on the "Risk Management Research Plan for Wet Weather Flows" (EPA, 1996), in concert with the Office of Water. The research plan was peer reviewed by the Urban Water Resources Research Council of the American Society of Civil Engineers and the Water Environment Research Foundation of the Water Environment Federation. By conducting an Environmental Technology Verification (ETV) pilot program on urban WWF control systems, ORD will expedite the development of WWF control technology and watershed management strategies (see Section 3.3).

The Office of Water's Office of Wastewater Management, Office of Science and Technology, and Office of Wetlands, Oceans, and Watersheds have parallel technology development and technology transfer programs that have been merged through joint management of projects of common interest. A portion of the WWF research plan's projects are being conducted collaboratively between the Office of Water and ORD, with funding from Section 104(b)(3) of the CWA.

4.3.2.3.4 Government Performance and Results Act Milestones

- **By 1999**, develop and evaluate indicator methods to describe toxic input to watersheds from WWFs.
- **By 2000**, develop methods to identify chemical stressors in toxic environmental mixtures.
- **By 2001**, publication of indicator methods to assess stream impacts from WWFs.
- **By 2002**, publish methods for diagnosis of multiple stressors in watershed ecosystems.

- **By 2003**, use condition and diagnostic ecological indicators to evaluate WWF management strategies in preventing degradation of water and sediment quality by contaminated run-off.
- **By 2003**, evaluate publicly available water quality simulation models to evaluate risks associated with various control technologies for WWFs in a watershed.
- **By 2003**, complete analysis of control technologies and their impacts on the watershed and associated risks.

4.4 Pesticides and Toxics

Government Performance and Results Act Subobjective:
Provide state-of-the-science measurements, methods, and models for development of ecological effects, exposure, and risk assessment tools, protocols, and guidelines and strategies and provide the scientific basis for credible ecological vulnerability assessments and evaluations of the impacts of environmental stressors

4.4.1 Background

The study of the deliberate release of toxic chemicals to control plant and animal pests always has been one of EPA's most important research programs. Thousands of pounds of pesticides are sprayed each year on crops and other components of the ecosystem to control the pests associated with agricultural production. The sophistication of the agricultural crop protection industry has produced an agricultural production system that is the envy of the world. The United States produces more goods in less "space" than any other country in the world, in part because of the extensive use of pesticides. Recognizing the significant risks posed by the deliberate release of "poisons", an elaborate registration and evaluation process is required before any pesticide can be used. This has led to the reduction in the use of persistent and chronically toxic compounds like DDT, which has brought about definite ecological improvements (e.g., the return of the bald eagle). The discontinuation of the use of a pesticide such as DDT is the result of a risk assessment process that recognizes the importance of the direct and long-lasting effects of these types of chemicals. As the use of persistent chemicals has diminished, newer and less persistent pesticides have become the dominant chemicals used in agriculture today. Many of these are not very persistent, do not accumulate in the environment, and, generally, are safer for the environment. They are, however, very acutely toxic and pose both direct and indirect effects on organisms and ecosystems. The SAB considers the use of these newer pesticides a local- to regional-scale risk, whereas use of the older, more persistent pesticides is viewed as a national- to global-scale problem. One of the most important assessment issues regarding pesticides today is the indirect or secondary effects associated with their use.

There are over 20,000 pesticide products (containing 620 active ingredients) on the commercial market. There are over 80,000 chemicals on the TSCA inventory, and, each year, an additional 2,000 chemicals are added. These agents can be found either singly or in various combinations in virtually every segment of the environment. Through the Ecosystems Protection Research Program, ORD develops the evaluative methods (effects, exposure, fate and transport, and risk assessment) that are used in the regulation of these environmental threats and in the understanding of their impacts to ecosystems. Test methods and measurements (environmental characterizations) developed through this program are incorporated into existing compendiums of test methods and assessment models used to support EPA's regulatory requirements. Both TSCA and FIFRA mandate that EPA issue test methods and guidelines and that these guidelines be periodically updated to incorporate significant scientific advances. This research program will develop and validate new methods and models and update existing methods and models to identify, characterize, predict, and assess ecological exposures and effects resulting from these environmental threats. Both the quality and quantity of data obtained for risk assessment are influenced directly by this research. Without these methods and models, EPA's statutory responsibility to protect the environment from unreasonable harm would be diminished. For a relatively small research and development investment, this program provides EPA's program offices with the means to obtain industry-generated data and establishes the necessary protocols, guidance, and assessment methodologies for making scientifically sound regulatory decisions.

This research program promotes several national environmental goals, including healthy terrestrial ecosystems, clean air, and clean water. Specific efforts to learn more about the potential health and environmental risks posed by these environmental agents (pesticides, toxics, and metals) support these major national goals and are consistent with the priorities and goals of the ORD strategic plan

Research under this area focuses on individual chemicals/toxics, classes of chemicals/toxics, and other issues that may pose serious risks to both human health or ecosystems; are expected to require a shorter term, concentrated effort; and are determined to be of special concern to EPA or the administration. In 1998 and beyond, research efforts will be broadened to incorporate effects, exposure, and assessment questions for determining the reliabilities, uncertainties, and impacts of broad classes of environmental agents, the evaluation of methods and models for determining the impacts resulting from cumulative exposures and effects of multiple chemicals within ecosystems and at various scales of ecological organization.

The current research being conducted in support of the Office of Pesticides and Toxics is focused on the ecotoxicological approach to risk assessment. Development and refinement of test methods for determining hazard, fate, and transport of toxic chemicals continues to be a need of this program. As newer toxic chemicals are produced with different modes of action, new test methods are needed to account for these new modes of action. Test methods for evaluating the effects at the ecosystem scale and extrapolating to other components of the ecosystem are needed for the future to better assess the risks to ecosystems and to the higher levels of biological organization.

4.4.2 Specific Research Focus

4.4.2.1 Test Methods

4.4.2.1.1 Statement of the Problem

ORD will work with the program office to develop test methods that do a better job of screening for chemicals that cause effects on the endocrine system. As the role of endocrine-disrupting chemicals becomes more apparent, the need to develop more precise test methods is needed. These test methods, to be developed within ORD's NHEERL, will undergo field validation and verification so they can be used in the risk assessment process.

Additional research is needed to better understand and interpret higher tier test data such as full field tests for avian effects and mesocosm data used to assess the risks to aquatic systems. Analysis of these complex data sets will be important in understanding the limitations of extrapolating from simple single-species tests to complex ecosystem-level responses.

4.4.2.1.2 Critical Questions for ORD Research

- Are screening tests reliable and available to identify and characterize the exposure and effects of pesticides and other toxic chemicals (inorganic and organic)?
- What is the reliability of current test methods for assessing the acute and chronic toxicities of sediment-bound pesticides and other toxic chemicals?
- What refinements of existing fate, transport, and exposure models are needed?
- How and where are probabilistic assessments needed to predict distributions of exposure rather than point estimates?
- What are the uncertainties of scaling (watershed to regional) on current risk assessments of the impact of pesticides and toxic chemicals?
- Are current exposure-assessment models adequate for assessing larger regional-scale impacts?
- What are the uncertainties and variabilities of indicator and biomarker measurements and methods of exposure and effects?
- How are indicator and biomarker methods of exposure and effects to be incorporated into regional-scale assessments and other multimedia exposure and effects assessment models?

- What is the next level of multimedia assessment models needed for determining the impacts and risks posed by environmental agents?

4.4.2.2 Indirect Effects

4.4.2.2.1 Statement of the Problem

Methods are needed to characterize and assess the indirect risks associated with pesticide use. For example, the synthetic pyrethroids (potent insecticides) are so powerfully toxic that they can wipe out all of the aquatic insects in nearby streams and lakes. Although they are not very toxic to fish, pyrethroids eliminate the food source of the fish and cause mortality by starvation (an indirect effect). Also, an entire field of insects can be eliminated with just one spraying, thus reducing or eliminating insect food for migratory birds. Herbicides have become so nontoxic to fish and wildlife, they usually pose little or no direct effects. However, they can drift into nearby riparian and fence row habitats and significantly reduce the ground cover of vegetation that is so important for wildlife species. These types of indirect effects now must be considered in pesticide regulatory decisions, and ORD will work together with the program office to develop the tools to adequately monitor and assess these indirect effects.

4.4.2.2.2 Critical Questions for ORD Research

- What are the indirect risks associated with use, exposure, and effects of toxic chemicals to ecosystems?
- How can the indirect risks associated with pesticide use be characterized and assessed?
- What new exposure and effects methods and modeling needs can be identified for assessing cumulative and aggregate exposures and effects of pesticides and toxic chemicals within ecosystems for incorporation into regional-scale assessments?

4.4.2.3 Place-Based Methods

4.4.2.3.1 Statement of the Problem

The emphasis on place-based assessment methods is a clearly stated, new direction in this research strategy. Although the program usually does not regulate toxic chemicals in this context, assessing the risks of chemicals at a biogeographical setting like a watershed will enable the program to add a "real world" component to their risk assessments. The emergency exemption provisions in the pesticide program are based in part on the place where the pesticide is to be used, and pesticide labels can be written to account for special places where use is prohibited, such as endangered species habitats.

4.4.2.3.2 Critical Questions for ORD Research

- Are new hazard tests needed for conducting place-based risk assessment?
- How can data be extrapolated from one place to another?
- How will the stakeholders be effected by a place-based approach?

4.4.3 Implementation

ORD's role is to develop the tools to conduct ecological risk assessments for toxic chemicals and pesticides. This is primarily an intramural program, with supplemental support provided by the extramural program. The intramural program will expand to incorporate new methods and modeling frameworks for assessing the cumulative impacts of multiple stressors (pesticides and toxic chemicals) into site- to regional- scale assessments. Through the generation of innovative indicator and biomarker measures of exposure and incorporation of predictive exposure and effects models, better risk assessments, reflecting lower uncertainties, can be applied directly to support regulatory and policy decisions associated with potential impacts of pesticides and toxics to ecosystems and evaluations of the vulnerabilities of major geographic ecosystems resulting from the cumulative and aggregate exposures to pesticide and toxic chemicals. The extramural program will concentrate on new monitoring methods and quantitative tools for linking multimedia assessments.

4.4.4 Government Performance and Results Act Milestones

- **By 1999**, provide updated methodologies and models for regional ecological exposure assessments.
- **By 1999**, develop and evaluate methods (indicators, biomarkers) for assessing population exposure and vulnerability to pesticides.
- **By 2000**, develop improved capability to assess the presence and risks of pesticides in watershed ecosystems.
- **By 2000**, publish methods at several levels of biological organization with specificity and sensitivity to diagnose the exposure of aquatic biota to individual pesticides and classes of pesticides.
- **By 2001**, complete development of ecological models for regional vulnerability assessments.
- **By 2001**, complete analysis of presence and physiological impacts of pesticides in aquatic biota.
- **By 2001**, publish indicator and biomarker methods for vulnerability of aquatic systems to pesticide exposure.
- **By 2002**, complete exposure assessment of ecosystem vulnerability to pesticide contaminants over regional scales.
- **By 2002**, publish molecular methods to analyze exposure to single and multiple pesticide stressors.
- **By 2003**, publish guidance for assessing ecological risks of pesticides and develop a landscape approach to assess ecosystem risk from pesticides and toxic substances.
- **By 2004**, provide indicator data to support pesticide exposure modeling on a large scale.
- **By 2005**, complete regional application of indicators for pesticides.

4.5 Hazardous Waste

Government Performance and Results Act Objectives:
EPA and its partners will reduce or control risks to human health and the environment, and facilities will be managed according to practices that prevent the releases to the environment

4.5.1 Background

Hazardous waste research in ORD is described in detail in the "Waste Research Strategy," which currently is undergoing peer review by EPA's SAB (ORD, 1997); therefore, the material presented in this section may be revised, based on the results of this review. Included in this strategy are descriptions of the problem and relevant ecological components of the program.

The number of RCRA waste management facilities is very large, and the risks they pose may be significant because of numerous releases of contaminants to the environment. In all cases, ecological risk assessments and related remediation or waste management steps are required. There are about 400,000 facilities that generate RCRA hazardous waste in the United States, and more than 5,000 facilities have been involved in the treatment, storage, and disposal of hazardous waste. These facilities, have approximately 100,000 solid waste management units that are potentially subject to the RCRA waste management program. In 1995, the United States incinerated approximately 48 million metric tons of municipal, pathological, and hazardous wastes. Additionally, there currently are about 300 municipal incinerators, 2,400 medical incinerators, 160 hazardous waste incinerators, 130 industrial furnaces, and 40 cement kilns that are burning these waste materials in various geographic locations throughout the United States. Spills and leaks of petroleum products and oils are also a serious problem affecting nearly every community in the United States.

Many waste sites identified on the Superfund National Priorities List (NPL) are large and constitute all or major portions of watersheds (e.g., Clark Fork, MT, contaminated with mining wastes and smelting operations, and the Carson River Basin, NV, contaminated with mercury from past mining operations). In these cases, ecosystems impacts and concerns greatly influence remediation approaches, cleanup levels, and remedy selection.

4.5.2 Specific Research Foci

Two broad research topics areas have been established that represent the major waste-related research problems for ecologically relevant research:

(1) contaminated sites—soils/vadose zone, and
(2) emissions from waste combustion facilities.

4.5.2.1 Contaminated Sites—Soil/Vadose Zone

Government Performance and Results Act Subobjectives:
Provide improved methods and dose response models for estimating risks from complex mixtures contaminating soils, and groundwater; provide improved methods for measuring, monitoring, and characterizing complex wastes in soils and groundwater; and develop more cost-effective and reliable technologies for cleanup of contaminated soils and groundwater

4.5.2.1.1 Statement of the Problem

The complexity and heterogeneity of soil/vadose zone matrices present a large number of technical challenges to their assessment and remediation. There are numerous uncertainties associated with soil/vadose zone decisions, and the cost of their remediation is still quite high (an average of $27 million per Superfund site in 1993). Local risks to humans and ecosystems, high costs, and uncertainty in decision making are all reasons for needing contaminated soil/vadose zone research.

4.5.2.1.2 Critical Questions for ORD Research

As was the case with groundwater, soils and the vadose zone are also extremely difficult to assess and characterize and costly to remediate. Specific scientific uncertainties and questions are associated with each step of the site evaluation and remediation process.

In the risk assessment process, major uncertainties and questions are related to

- magnitude of effects on ecosystems;
- contributions of indirect pathways to receptor exposure; and
- availability of adsorbed contaminants and treatment residuals to ecological receptors.

In the site characterization process, major uncertainties and questions are related to

- sampling of contaminants to determine their location and magnitude;
- quantitative analysis of selected compounds,
- design of site-specific sampling strategies, and
- physical characterization of soils and the vadose zone.

In remediation, major uncertainties and questions are related to

- applicability of treatment techniques to different contaminants and soil matrices, particularly heterogeneous matrices, and
- cost of remediation techniques.

4.5.2.1.3 Implementation

In response to the above uncertainties and questions and to the research needs identified by the client offices (Office of Solid Waste and Emergency Response [OSWER] and the regions), ORD has identified 12 research activities related to ecological risk. These are listed in priority order in Table 4-1. All of these research activities are conducted primarily by ORD scientists and are in the FY97 base research program, except for mixtures toxicology and estimating soil intake and dose for wildlife species.

Table 4-1. Research to support soil and vadose zone assessment and remediation.

Research Activity Title	Potential Research Focus
(1) Biotreatment	• Determine under what conditions biotreatment processes can reach risk-based cleanup levels • Develop less expensive cleanup processes for frequently found hard-to-treat contaminants • Develop inexpensive permanent cleanup options for land fills • Determine when natural attenuation is an appropriate remediation option for soils and landfills
(2) Estimating Soil Intake and Dose for Wildlife Species	• Develop critical ecological exposure factors such as species-specific soil intake rates, uptake factors from soils to plants to herbivores, species-specific dietary factors, uptake factors from herbivores to carnivores, and data on migratory and range patterns • Develop a wildlife-contaminant exposure model that should be useful for constructing and evaluating site-specific scenarios (This model would allow calculations of intake via the food web, the analysis of multiple exposure pathways and species, and also would include a probabalistic component to evaluate variability and uncertainty.)
(3) Field-Sampling Methods	• Develop sampling methods that better preserve the integrity of contaminants in soil (e.g., VOCs) • Develop sampling approaches to better ensure that a sample is "representative" of the area surrounding the sample location
(4) Field and Screening Analytical Methods	• Develop field-portable methods for rapid in situ determination of contaminants in soils • Develop analytical methods to determine the status and rates of natural attenuation in soils
(5) Containment	• Develop methods for evaluating the long-term effectiveness of containment systems • Develop more cost-effective containment systems
(6) Ecological Screening Tests to Measure Effectiveness of Treatment	• Develop inexpensive methods to screen for significant risks from treatment residuals • Develop inexpensive methods to determine cleanup goals
(7) Sampling Design	• Develop new statistical designs for sampling/characterizing contaminated soils at waste sites (e.g., multivariate, three-dimensional technologies)
(8) Demonstration/Verification of Innovative Remediation Techniques	• Produce technically sound performance, cost, and applicability data for full-scale innovative remediation techniques
(9) Demonstration/Verification of Innovative Monitoring Technology	• Produce technically sound performance data for innovative soil monitoring and characterization technologies
(10) Abiotic Treatment	• Develop less expensive cleanup processes for hard-to-treat contaminants and matrices
(11) Mixtures Toxicology	• Develop improved models of the synergistic/antagonistic effects of common soil- contaminant mixtures
(12) Oil Spills	• Develop more effective ways to remediate spills in an environmentally safe manner

4.5.2.2 Emissions from Waste Combustion Facilities

Government Performance and Results Act Subobjectives:
Provide improved multimedia, multipathway exposure and risk models for estimating risk from waste, waste streams, and waste facilities; and provide improved techniques to control and prevent emission formation from incinerators and industrial systems burning wastes

4.5.2.2.1 Statement of the Problem

Currently, there are 307 municipal waste combustion facilities with a capacity of 104,000 tons per day in the United States. About 30 million people in 35 states and 900 communities are served by municipal waste combustion facilities. This accounts for approximately 16% of the waste generated annually. These facilities are known to emit toxic contaminants such as dioxin, furans, cadmium, lead, and mercury. In addition to large municipal waste combustion facilities, there are thousands of small incinerators, such as those used to dispose of medical wastes. Recent studies indicate that medical waste incinerators are likely a major source of mercury emissions. There are also approximately 150 facilities combusting hazardous wastes and approximately 50 incineration units being used to clean up Superfund and RCRA corrective action sites. All of these units are burning complex mixtures of toxic contaminants, often in high concentrations and, therefore, can contribute significant emissions on a site-specific basis if improperly designed and operated.

The risks associated with combustion facilities are potentially very high because of the large number of combustion facilities, the facilities emit very toxic contaminants, these emissions become dispersed over large geographic areas that often have large populations or produce important food products (crops, animals, and dairy products), and exposure occurs over several pathways and routes. These risks also are perceived by the public to be very high, as evidenced by community protests at facilities such as Waste Technologies Incorporated in East Liverpool, OH, and at many Superfund sites, such as New Bedford Harbor, MA, and Bloomington, IN.

4.5.2.2.2 Critical Questions for ORD Research

The risks associated with combustion facilities are also highly uncertain and cut across the risk assessment paradigm. Areas of major uncertainty in exposure assessment include

- What contaminants are being released during emissions? What additional contaminants are formed as the emissions disperse and are transformed in the environment?
- What is the fate and transport of the contaminants? Where do they go, and who might be exposed?
- What is the geographical scale of exposure? (Current studies indicate that airborne contaminants are extremely mobile and can affect regional receptors.)
- To how much contaminants are people and ecological receptors exposed, and through what exposure pathways? How much contamination eventually makes its way into food? How much of the contamination found in food is bioavailable to cause a toxic response in human receptors?
- How effective and accurate are current monitoring technologies?

The area of major uncertainty in toxicity assessment is

- How harmful to ecological receptors are the contaminants that are being released? What amounts of dioxin, furans, mercury, lead, cadmium, and other stressors are harmful?

The areas of greatest uncertainty in risk management are as follows:

- How can emission levels of contaminants be most cost-effectively reduced?
- What are the combustion processes that lead to contaminant formation?
- Are process design/operation changes appropriate, or should add-on controls be used? What are the least expensive ways to minimize emissions from small combustors? How can the control of multiple emissions be most cost-effectively accomplished?

4.5.2.2.3 Implementation

In response to the above uncertainties and questions and to the research needs identified by the client offices (OSWER and the regions), ORD has identified six research activities related to ecological risk. These are listed in priority order in Table 4-2 below. None of these activities is part of the FY97 base research program. These research activities are candidates for funding as grants through ORD's STAR program and through reallocation of base resources in FY99.

Table 4-2. Research to support emissions from waste combustion assessment and remediation.

Research Activity Title	Potential Research Focus
(1) Emission Prevention and Control	• Develop a better understanding of the combustion processes that lead to emissions formation • Characterize toxic emissions from industrial hazardous waste combustion units • Determine the most cost-effective means of controlling emissions from hazardous waste combustion units, especially industrial units and small incinerators
(2) Indirect Exposure Characterization/Modeling	• Determine the fate and transport of emission contaminants • Develop models that identify and predict the formation of secondary contaminants from primary emissions
(3) Indirect Pathway Risk Assessment Methods	• Test and validate indirect exposure methodology (IEM), using site-specific data • Develop and validate contaminant biotransfer and uptake factors • Develop guidance manuals and software program to apply IEM procedures
(4) Continuous Emissions Monitoring Methods	• Develop improved instruments that measure (on a "real-time" basis) what contaminants are being released to the environment
(5) Dose Response of Key Contaminants	• Complete the toxicity assessment of mercury • Develop toxicity values (reference doses, reference concentrations, cancer slope factors) for critical contaminants
(6) Studies of the Movement of Bioaccumulative Chemicals in Food Webs	• Determine ecological effects of metal emissions • Study the movement of mercury in aquatic environments • Determine bioavailability of metals

4.5.3 Government Performance and Results Act Milestones

EPA and its partners will reduce or control risks to human health and the environment.

- **By 2000**, complete six Superfund Innovative Technology Evaluation (SITE) demonstrations.
- **By 2001**, publish guidance on improved sampling methods for contaminants in soils.
- **By 2002**, publish guidance on improved noninvasive geophysical methods and techniques to detect and delineate contaminants in the subsurface.
- **By 2003**, complete development of improved screening and field-portable analytical technologies and methods for detection and quantitation of inorganic and organic contaminants in soil and groundwater.
- **By 2003**, provide improved remote sensing methods for characterizing waste sites.
- **By 2008**, provide integrated site characterization guidance and software.

Facilities will be managed according to practices that prevent the releases to the environment.

- **By 1999**, produce a guidance document for evaluating indirect exposure from incinerator emissions.
- **By 2000**, complete development of improved version of the Hazardous Waste Identification Rule (HWIR) multimedia, multipathway modeling methodology for assessing exposures associated with listed waste constituents.
- **By 2000**, provide monitoring guidance related to exit values.
- **By 2001**, develop an expert software system to implement guidance for evaluating indirect exposures from incinerator emissions.
- **By 2003**, complete development of multimedia, multipathway exposure and fate models for integrating human and ecosystem exposure and risk over time and space.

4.6 Multimedia Research

4.6.1 Background

As documented earlier in the strategy, there is an increasing need to evaluate more holistic issues of environmental protection. Problems have grown in both scale and complexity to the point where managing them may be more likely than solving them. Therefore, the multimedia research area, the largest of ORD's resource categories, focuses on issues that are multimedia, multistressor, or multireceptor in nature. As such, much of the research in this category is related most directly to the core program discussed in Section 3. However, some projects of particular interest to both ORD and EPA are described below in more specific terms than in the core program.

The highest priority areas for research in this area are

- global climate change,
- UV-B,
- endocrine disruptors,
- habitat modification and restoration,
- exotic species,
- anthropogenic nitrogen, and
- regional risk assessment.

4.6.2 Specific Research Foci

4.6.2.1 Global Change Research

Government Performance and Results Act Subobjective:
Provide the capability to assess ecological and associated human health vulnerability to climate-induced stressors at the regional scale and assess mitigation and adaptation strategies

4.6.2.1.1 Statement of the Problem

Human-induced factors now are recognized formally by the international scientific community to significantly influence climate change, leading to unprecedented rates of warming over the next century (IPCC, Second Assessment Report, 1995). In 1990 and 1995, the multinational IPCC group summarized the consensus state of knowledge and major uncertainties in the science of global climate change. The detailed impacts of climate change are still uncertain, and EPA, along with other federal agencies coordinated through the USGCRP and the international community, have a substantial program underway to determine the degree of vulnerability of natural ecological systems and human health and the socioeconomic consequences of the anticipated changing climate.

4.6.2.1.2 Critical Questions for ORD Research

EPA's research program is directed towards understanding the vulnerability of regional-scale ecosystems to climate change in the context of other stressors. EPA plays a unique role in the interagency global change research community because EPA promotes environmental protection for the benefit of human health, as well as that of global ecosystem integrity. ORD's Global Change Research Program will focus on integrated assessments of the potential ecological risks of climate change to coastal, freshwater, and terrestrial ecosystems throughout the United States, and then extend the analysis to include implications for human health. EPA will concentrate on studying *regional-scale* ecosystems with their embedded landscape mosaics because (1) regional analyses may be more readily linked with policy development, and (2) the ecological mechanisms causing an observed effect can be best identified on a regional scale.

ORD's Global Change Research Program design is twofold: (1) to improve the scientific basis for evaluating important ecological and human health impacts of climate change by analyzing the regional ecological vulnerabilities to temperature and hydrologic changes associated with projected climatic changes in the context of other stressors, and (2) to develop programs to reduce the most significant risks posed by climate change by identifying and evaluating the cost-effectiveness of global change mitigation and adaptation strategies in target areas of the United States.

Specifically the questions for the research program include

- What are the best indicators (sentinels) of climate change at population, community, and ecosystem levels of organization?
- What future coastal ecological vulnerabilities, on a range of spatial scales, result from the joint effects of changes in climate, sea level, and other stressors, such as pollutants and land use?
- How do climate-induced changes in biogeochemistry affect species distribution and diversity; productivity; sustainability; and integrity of terrestrial, freshwater, and coastal ecosystems?
- How does global climate affect watershed processes?
- How do climate-induced changes in temperature, moisture, and atmospheric composition affect biogeochemistry of regions or ecosystems?
- What are the regional-scale projections of climate change?
- How will climate change affect human health directly and indirectly, via ecologically mediated factors?
- How do the vulnerabilities of natural systems to global climate change influence regional economies?
- What civil and environmental infrastructures are most likely to be impacted by global change?
- What options are available for adapting ecosystems to climate change?
- What technologies are most appropriate for greenhouse gas reductions?
- What are the costs and benefits of new technologies to replace refrigerants?

4.6.2.1.3 Implementation

ORD will achieve its Global Climate Change Research Program mission through a combination of research by the laboratories and centers, including (1) basic experiments of climate change impacts on biogeochemical cycles in a variety of ecosystems, (2) modeling efforts to project climate scenarios, (3) high-technology, manipulative experiments on tree seedlings, (4) modeling efforts of watershed processes, (5) risk and integrated assessments of climate change impacts, and (6) comparisons and evaluations of greenhouse gas reduction technologies. This research will be done by a combination of in-house researchers and those who are funded by EPA's extramural grants program.

4.6.2.1.4 Government Performance and Results Act Milestones

- **By 1999**, using remotely sensed processes, provide a hybrid method to classify and label and cover and land cover pattern change.
- **By 2000**, contribute to an assessment of the impacts and consequences of climate change on a regional scale. This assessment will be conducted under the auspices of the USGCRP.
- **By 2000**, completion of STAR grants awarded in FY95 (regional hydrologic vulnerability) and FY96 (integrated assessments).
- **By 2001**, publication of significant research findings from mesocosm experiments and field and modeling studies.
- **By 2001**, complete a comparison of greenhouse gas emission reduction alternatives.

- **By 2002**, analysis of North American Landscape Characterization (NALC) data for change indicators.

4.6.2.2 UV-B

Government Performance and Results Act Objective:
Ozone concentrations in the stratosphere will have stopped declining and slowly begun the process of recovery

4.6.2.2.1 Statement of the Problem

The release of CFCs to the atmosphere has led to the thinning of the stratospheric ozone layer around the globe and to the "ozone holes" over the Poles. The stratospheric ozone layer filters out much of the harmful UV radiation before it hits the earth's surface; so, as the ozone layer thins, higher levels of UV radiation actually can hit the earth's ecosystems and humans. This UV radiation can cause significant damage to plants and animals, including humans, through such mechanisms as impairing critical physiological functions (e.g., photosynthesis), causing skin cancers, and reducing the immune response in humans.

4.6.2.2.2 Critical Questions for ORD Research

Resources for UV-B will be used to enhance research in the evaluation of the biological effects of UV-B. This enhancement will leverage off the integrated long-term monitoring network being developed in conjunction with the CENR. Data collected via this network will be used to determine the occurrence and distribution of UV-B and to perform trends analyses. Research also will focus on the effects of UV-B on aquatic and terrestrial systems, including the biological effects of UV-B on sensitive biota (e.g., amphibians). The indicators research will include freshwater watershed indicators, such as (1) the degree of shading or watershed retention time; (2) terrestrial indicators of forest integrity and sustainability in response to multiple stressors; and (3) estuarine indicators, such as changes in community trophic levels resulting from temperature changes. Further research efforts will focus on determining which technological advances would have the greatest incremental impact on greenhouse gas emissions and will leverage funding available in other federal agencies and industry to catalyze the development and demonstration of the most promising no- or low-global-warming technologies.

Key questions include

- What are the effects of UV-B on amphibians?
- What factors are of primary significance in decreasing the effect of UV-B exposures to terrestrial, freshwater, and estuarine biota?
- What factors affect UV-B exposures?
- What are the trends in UV-B at index locations?
- What models are best for forecasting UV-B exposures at multiple scales?

4.6.2.2.3 Implementation

ORD will develop both a monitoring program to measure regional levels of UV-B radiation (four sites are already are underway, and a number of additional sites, in rural and urban locations spread across the country, also are planned) and a research program to examine the effects of UV-B radiation on sensitive plant and animal species, such as humans and amphibians. ORD's UV-B monitoring network and effects research will be supported by ORD's global change budget. The sites themselves will receive additional funding through the EMAP program, although the instruments for monitoring UV-B radiation and the research examining the effects of UV-B radiation on ecological systems and human health fall under the regional vulnerabilities component of the Global Change Research Program.

4.6.2.2.4 Government Performance and Results Act Milestones

- **By 2002**, provide improved radiative transfer models for measuring UV exposure.
- **By 2002**, provide initial analysis of changes in stratospheric ozone concentrations.

- **By 2003**, provide a summary of UV monitoring data at urban and rural sites.

4.6.2.3 Endocrine Disruptors

Government Performance and Results Act Subobjective:
Identify and evaluate strategies to manage risks from exposures to endocrine-disrupting chemicals capable of inducing adverse reproductive and other effects in wildlife

Evidence has been accumulating that humans and domestic and wildlife species have suffered adverse health consequences resulting from exposure to environmental chemicals that interact with the endocrine system. Collectively, these chemicals are referred to as endocrine-disrupting chemicals (EDCs). EDCs have been defined as exogenous agents that interfere with the production, release, transport, metabolism, binding, action, or elimination of the natural hormones in the body responsible for the maintenance of homeostasis and the regulation of developmental processes.

4.6.2.3.1 Statement of the Problem

Despite reported adverse reproductive and immunological health effects, little is known about their causes and the concentrations of EDCs that would induce effects in various populations. Nevertheless, it is known that the normal functions of all organ systems are regulated by endocrine factors, and small disturbances in endocrine function, especially during certain stages of the life cycle, such as development, pregnancy, and lactation, can lead to profound and lasting adverse health effects. Based on recognition of *the potential scope of the problem*, *the possibility of serious effects on the health of populations*, and *the persistence of some endocrine-disrupting agents in the environment*, research on endocrine disruptors was identified as one of the six high-priority topics identified in the ORD strategic plan (EPA, 1996). If future health effects and exposure studies conclude that humans and the ecosystem are at significant risk because of exposure to EDCs, research on how best to lower or eliminate the risk will be needed.

4.6.2.3.2 Critical Questions for ORD Research

For ecological concerns, the primary questions that need to be answered about endocrine disruptors are shown below.

- What effects are occurring in exposed wildlife populations?
- What are the chemical classes of interest and their potencies?
- Do current testing guidelines adequately evaluate potential endocrine-mediated effects?
- What extrapolation tools are needed?
- What are the effects of exposure to multiple EDCs?
- How, and to what degree, are wildlife populations exposed to EDCs?
- What are the major sources and environmental fates of EDCs?
- How can unreasonable risks be managed?

Ecological Effects Research

Recently, two environmental laws were enacted that specifically require the testing of pesticides and other chemicals found in or on food or in drinking water sources to determine their ?estrogenic or other endocrine effects in humans." The Food Quality Protection Act of 1996 (FQPA) and the Safe Drinking Water Act Amendments of 1996 (SDWA) require EPA to develop, within 2 years of enactment, a screening program using validated test systems to determine whether substances may have estrogenic or other endocrine effects on humans. The screening program must undergo a public comment period and peer review and be implemented within 3 years. The laws require that the manufacturers, registrants, or importers conduct the testing of the pesticides and other substances according to the program that EPA develops. The question remains as to whether the screening program needs to include a test specifically related to detection of endocrine disruption in wildlife or whether an approach targeted to address human health would be sufficient to address broader concerns.

The development of a comprehensive, reliable, and scientifically sound screening program for endocrine disruptors is a complicated task. There is a clear need for the development of appropriate screening tests for estrogenic substances, as well as for other chemicals that may adversely affect the endocrine system. In fact, this was identified as a high-priority research need at two EPA workshops in 1995. A number of tests have already been developed that purport to detect and identify chemicals with certain endocrine-disruption activity. As a first step in developing a screening program, an objective evaluation of these tests to determine their technical merits and limitations for detection of endocrine-disruption activity has already begun, with EPA among the assessors. The results of this effort will be important to decision makers in making informed decisions about developing a screening program for endocrine disruptors. If the existing tests are not sufficiently validated (as is likely the case), more evaluation of their practical utility will be needed. If new tests must be developed, they also will need to be validated

The broad objectives of the strategy to evaluate the ecological risk of EDCs are twofold:

(1) determine EDC risk relative to risk from other stressors on populations and communities, both prospectively and retrospectively, and
(2) develop or modify methods for testing and evaluating chemicals and environmental samples to ensure that those exerting toxicity through specific endocrine axes will be characterized.

Both objectives require a reduction in uncertainty in prediction of risk across levels of biological organization, including better linkage of measurement and assessment endpoints. The objectives also require an increased understanding of processes and species at risk, including an understanding of modes of action suspected to exert toxicity through endocrine axes. Moreover, ideally there should be overlap of measurements made across different monitoring efforts. This type of coordination, although not necessarily a research issue, is very important from the standpoint of a coherent approach to risk assessment and management decisions concerning EDCs.

In defining the specific role of ORD in endocrine disruptor research, it is important to note that there are clearly important areas for which other federal agencies have the research lead (e.g., National Cancer Institute and Centers for Disease Control and Prevention for studies on environmental causes of breast cancer, NOAA for immunological effects in marine mammals, National Sanitation Foundation and National Institute for Environmental Health Sciences for the role of hormones in the normal differentiation of the brain and reproductive track). Conversely, because of their scope and complexity, other problem areas need to be approached by multiple organizations (e.g., development of short-term screening techniques, determination of environmental contamination levels). ORD has selected those areas where EPA should be playing at least a moderate role. Developing methods for performing hazard and risk characterization of chemicals, quantitating exposure levels, determining environmental fate and transport of chemicals, and developing extrapolation tools have been traditional strong points of the EPA research program. It is in these areas that the first contributions are proposed to the overall scientific effort. If biological effects and exposure research concludes that the ecosystem is at significant risk because of exposure to EDCs, research on how best to lower risks will be needed. Because sources of known EDCs are poorly characterized, little is known about the effectiveness of current controls to minimize emissions. For some, current emission control approaches may be inadequate or too costly; for others, new approaches might be needed to avoid use. As the EDC research program matures, a progressive increase in attention to risk management activities is anticipated. To better assess the ecological risks of EDCs, work needs to be done to define linkages between potential measures of effect (usually made at the level of the individual) and assessment endpoints (which typically are at population or community levels). Similarly, linkages between these measures at different levels of biological organization need to be better defined. For example, induction of vitellogenin in male fish appears to be a very specific response to exposure to estrogen mimics; however, it is unclear what this means in terms of reproduction. The basic challenge in this research area is to identify those measures that are both indicative of exposure to EDCs and predictive of their effects in populations. Furthermore, we must develop a better definition of "normal”, with respect to endocrine-regulated processes in commonly tested or monitored species, relative to effects manifested at the population level (e.g., the degree to which circulating levels of sex steroids need to be altered before reproductive success is threatened).

Available measures of effects, exposure, and organism and ecosystem characteristics for ecological risk assessment need to be adapted to classes of organisms that have received little attention in terms of traditional toxicity test methods and approaches, such as amphibians, nonteleost fish, and passerine birds. Two objectives are addressed here:

(1) better development of a comparative endocrinology/toxicology database, and

(2) better definition of baseline conditions for general processes and specific endocrine function.

Without this, the usefulness of comparative endocrinology as a basis for assessing the ecological risk of EDCs is significantly decreased. To characterize the relative risks of EDCs from an ecological perspective, it is necessary that there be a high degree of consistency in data collected. This becomes critical in terms of coordinating existing monitoring programs so that biological endpoints should include effects that are indicative of the impact of EDCs on individuals and populations, and chemical characterization should include those xenobiotics.

Exposure Research

The pathways between source and exposure to EDCs are complex. Many of the suspected EDCs studied to date are organic compounds or organic forms of a few heavy metals that are persistent and can bioaccumulate and biomagnify in the food chain. Knowledge of the nature of these factors is basic to predicting future exposures and the efficacy of exposure prevention strategies. For example, slight variations in chemical form and physicochemical characteristics (e.g., planarity, isomerization, polarity) may manifest themselves in various ways that affect exposure (e.g., differences in transport and routes of exposure, increased or decreased bioavailability, changes in exposure pathways, potential for atmospheric and hydrological transformation, and fate).

Another major challenge is the need to understand complex exposure patterns, rather than simple net annual exposure. As discussed in the effects section of the ORD Research Plan for Endocrine Disruptors (EPA, 1996), there are certain to be windows of vulnerability to exposure because of temporal and seasonal patterns of endocrine functions. For example, exposure to one EDC during an animal’s mating season may have significant effects, whereas for another EDC, exposure during gestation is more crucial. Therefore, ORD will conduct exposure research of endocrine disrupting substances within EPA’s risk assessment framework and will explore methods and models to measure and predict exposure to these substances.

At the outset, ORD’s exposure research will emphasize three areas. The first involves better physico-chemical characterization of a few known or highly suspect EDCs to obtain a better near-term understanding of the potential effects of chemicals of current concern. The second area is developing pathway models (e.g., compartmental transport, fate, or transformation) for chemicals that are likely to be endocrine disruptors. In both of these areas, existing data, information in the public literature or in EPA data files, and model resources will be searched and evaluated to establish current capabilities and to identify data gaps and uncertainties before new parameters and models are developed. The third area is to reduce uncertainties in the flux of EDCs in and out of sediments, a major exposure source for many bioaccumulative compounds.

The key questions that must be answered in accord with ecosystem protection with references to sections in the ORD Research Plan for Endocrine Disruptors (EPA, 1996) are as follows:

- What are the chemical classes of interest, and what are their potencies?
- What extrapolation tools are needed?
- How, and to what degree, are human and wildlife populations exposed to EDCs?
- What are the major sources and environmental fates of EDCs?

4.6.2.3.3 Implementation

Recognizing that integration of the intramural research program with the extramural grants funded by the EPA STAR Program is crucial to effective resource utilization, project elements were partitioned between the two components on the basis of the availability of expertise within the intramural program (do we have laboratories capable of undertaking the research?), the track record of research programs (do we have scientists currently working in these areas?), the magnitude of the research question (what is the scope of the effort needed to study the problem?), and the timeframe in which answers would be needed (does the intramural program have the capacity to accomplish goals in a timely manner?). Topics most appropriate to assign to the intramural program include dose-response and mode-of-action studies on the development of the reproductive tract, central nervous system, and immune system in laboratory species; establishing a framework for multilaboratory EDC studies to identify priority chemicals and exposure pathways, characterizing EDC exposures and action at selected near-laboratory sites; determination of EDC fate and transformation in sediments; and developing risk management tools for risk reduction or prevention. Examples of areas where interaction with the external scientific community is particularly important include developing short-term test methods for hazard identification and describing modes of action, studying the role of hormones in sexual differentiation of nonmammalian species, and identification and utilization of sentinel species. These issues are addressed in greater detail in the ORD EDC research strategy.

It is presumed that investigator-initiated responses to requests for assistance derived from this research strategy will provide the basis on which the expanded ORD research effort in endocrine disruption will be built. From these submissions, projects will be selected for funding on the basis of both scientific excellence and programmatic relevancy, using criteria provided below. A similar, parallel process will be used to target the RFAs in the STAR program and to select grants for funding.

The scope of the endocrine disruptor problem suggests that continued oversight of the ORD effort will be required to maintain an appropriate balance among the various components of the research plan and to ensure that the major data gaps are addressed. The danger in a program developed largely through investigator-initiated activities, even within a defined topic such as endocrine disruption, is that the individual components do not complement each other sufficiently to achieve the overall goals that are stated in the introduction to this document. To help avoid this potential problem, the individual national laboratories and centers are expected to develop specific implementation plans for addressing the research needs. These plans should be reviewed for their ability to provide a useful and integrated research output to the program offices. Annual reports of progress and presentation of the upcoming research objectives from each laboratory and center will facilitate the exchange of information within ORD, assist in the direction of work to the highest priority areas, and help fine-tune the research directions as new information from the program emerges. For example, research related to risk management actions was given only a "medium" priority in the research plan, pending resolution of the extent of the endocrine disruption problem. Such efforts are likely to grow in importance and merit a higher priority for funding. Conversely, other topics may fade in importance as the key uncertainties are addressed. Interactions between the recipients of the STAR grants and the intramural investigators involved in endocrine disruptor research also are encouraged through such mechanisms as annual or biannual workshops, to further the exchange of information and to expand collaborations.

4.6.2.3.4 Government Performance and Results Act Milestones

- **By 1999**, explore molecular and genetic methods to detect compounds that interact with the endocrine system.
- **By 2000**, expands the environmental scanning project to involve regional and program offices.
- **By 2000**, initiate an environmental scenarios project to draw implications from selected environmental trends.
- **By 2000**, publish preliminary findings of molecular interaction with EDCs in wildlife.
- **By 2000**, develop a preliminary EDC fate and transport model.
- **By 2000**, complete the external review draft of the Oxides of Nitrogen Air Quality Criteria Document.

- **By 2001**, expand the environmental scenarios project to involve regional and program offices.
- **By 2001**, develop and apply indicator methods to detect exposures of wildlife to compounds that interact with the endocrine system.
- **By 2001**, evaluate indicator methods for endocrine disruptors at a local Asource-based" scale.
- **By 2003**, construct QSAR models of steroid receptor interaction and laboratory animal models of endocrine-disruptor-induced diseases.
- **By 2003**, define modes of action for EDC classes on critical target organs.
- **By 2003**, identify opportunities for joint effect/exposure field studies related to EDCs.
- **By 2003**, apply ecological indicator methods for endocrine disruptors at regional scales.
- **By 2003**, develop an EDC model that includes exposure and effects linkages.
- **By 2004**, develop methods and models to identify hazards and estimate dose-response actions specifically related to synergistic action of EDCs.
- **By 2004**, define the shape of the dose-response curve for EDCs in the low-dose region.
- **By 2004**, identify significant exposure pathways for EDCs.
- **By 2004**, complete field efforts linked to hypothesis-driven laboratory studies related to EDCs.
- **By 2004**, complete written guidance on methodologies to integrate human health and ecological risk assessments.
- **By 2004**, link field efforts in EDC indicators to field effects observations and provide data for modeling.
- **By 2005**, deliver information/understanding to assist in identifying, modeling, measuring, and controlling air pollutant mixtures.
- **By 2008**, ORD evaluates cost-effective methods for prevention and control of identified EDCs.

4.6.2.4 Exotic Species

Government Performance and Results Act Objective:
Emerging risk issues

4.6.2.4.1 Statement of the Problem

About one in seven species (plants, animals, and pathogens) that are inadvertently brought into this country become invasive, leading to problems that cost billions of dollars in attempts to correct them. About a fourth of America's agricultural production is lost each year to foreign plant pests and the costs of controlling them. The costs to natural systems when alien plants or animals come to dominate can be staggering. Keeping all alien species out of the country is an impossible task, but it is far more difficult and costly to deal with invasive species once they are established.

Increased world commerce and travel, coupled with more extensive use of the land and lakes and rivers, have transformed the once academic concern about alien species into a practicable and exceedingly costly problem for the United States. Because of its low profile in relation to many other ecological concerns, the problem of introduced species is not widely appreciated. However, some now concede that invasive alien species are a greater problem than habitat loss and chemical contamination. Recognizing this, the U.S. government created the Aquatic Nuisance Species Task Force, which is charged with implementing the Aquatic Nuisance Species Control Act of 1996. The act was passed because of the growing concern that nonindigenous species may be posing significant threats to sustainable ecosystems.

4.6.2.4.2 Critical Questions for ORD Research

Currently, the key questions for this area of research are focused on hazard identification. The issues that need to be addressed include

- Should this country be concerned about alien species?
- Why are alien introductions any more of a problem than the natural movement and expansion that have always characterized plant and animal species?

- What and who are at risk when an introduced species becomes invasive?
- What steps can be taken to limit harmful introductions, and what can be done to reduce the damage once the alien species are here?
- Are present controls adequate?

4.6.2.4.3 Implementation

ORD's role is to conduct ecological risk assessments for the control programs that are proposed to deal with certain species. For example, piscicides, (fish-killing pesticides) have been proposed as a control method to reduce the impact of invasive fish (e.g., round golby and Eurasian ruffe) that have become a problem in the upper Midwest. It is important to compare the risks of using pesticides to reduce the invasive species to the risks of the invading species themselves. ORD's knowledge and experience in conducting risk assessments will continue to be supplied by the intramural portion of the program. An extramural component is anticipated to deal with the broader aspects of alien species, their life histories, and control options and costs, following the completion of the hazard evaluation.

4.6.2.4.4 Government Performance and Results Act Milestones

A section on exotic species will be included in the final ecological risk assessment guidelines that will be published in the fall of 1997.

4.6.2.5 Anthropogenic Nitrogen

Government Performance and Results Act Objectives:
Restore and protect watersheds, develop tools to reduce loadings, improve water quality, and reduce ambient nitrates and total nitrogen deposition by 5 to 10%

4.6.2.5.1 Statement of the Problem

The amount of biologically active nitrogen circulating in the biosphere has increased dramatically during the last several decades. Increasing use of industrial fertilizers, increased cultivation of nitrogen-fixing crops, deforestation, wastewater disposal, and fossil fuel combustion have contributed to increasing loads of nitrogenous compounds to the world's ecosystems. On an annual basis, anthropogenic sources of fixed nitrogen now account for more than half the biologically active nitrogen entering terrestrial, freshwater, and coastal marine ecosystems. Although the short-term effects of nutrient overenrichment are reasonably well known, the long-term effects of altering the ecological cycling of this important nutrient element are not well understood. For example, the roles of nitrous oxide in stratospheric ozone depletion and of sewage nitrogen in coastal eutrophication are fairly clear. However, recent findings have implicated nitrogen overenrichment as a causal factor in reducing aquatic and terrestrial biological diversity and, perhaps, in triggering noxious algal blooms. Questions about how nitrogen additions affect the structure and function of ecosystems over a range of timeframes and spatial scales need to be answered to identify particularly vulnerable parts of the landscape and to protect these systems from harmful effects of nitrogen overenrichment.

The current ability to protect vulnerable ecosystems by controlling the amount of nitrogen released on land, to the air, or into water, will be limited by uncertainties surrounding the nature and extent of the harmful effects of nitrogenous compounds (acting singly or in combination with other pollutants) on the structure and function of terrestrial and aquatic ecosystems. The magnitude of the nitrogen-emission problem remains uncertain. The ability to quantify the ecological changes that occur as the flux of fixed nitrogen to the nation's ecosystems increases is not known. And, as a result, there is no ability to accurately predict the ecological benefits to be gained by reducing nitrogen emissions.

ORD's research related to nitrogen emissions needs to focus on identifying the critical areas of scientific uncertainty in the terrestrial and aquatic nitrogen cycle and on developing better scientific tools for evaluating, understanding, and predicting the ecological effects of changes in the loadings of nitrogen on the nation's most susceptible watersheds and bodies of water. The biogeochemistry of nitrogen is very complex, and potential problems traverse atmospheric, terrestrial, and aquatic media. To make progress, the program requires a balance of solid fundamental scholarship, empirical studies, well-targeted monitoring data, simulation modeling, and mechanistic studies.

4.6.2.5.2 Critical Questions for ORD Research

(1) How can it be determined that an ecological "problem" is caused by nitrogen inputs and not by some other environmental stressor or factor? What are the best indicators of nitrogen effects on terrestrial and aquatic ecosystems?

The problem-formulation stage of ecological risk assessment requires the development of techniques and indicators that will allow environmental managers to determine when a system is at risk from nitrogen overenrichment. ORD's research on nitrogen needs to develop diagnostic indicators that identify systems currently or potentially at risk from nitrogen stress. Over the past several decades, research on nitrogen dynamics in North America and Europe has led to major advances in the understanding of nitrogen dynamics and in the identification of many potentially useful indicators of nitrogen "enrichment status". Nitrogen-content and elemental ratios of leaves and forest litter, variations in stable isotopic compositions of nitrogen pools in the environment, and many other potentially useful indicators need to be tested for their generality and accuracy.

(2) How much nitrogen enters the nation's terrestrial and aquatic ecosystems?

In addition to being able to ascertain whether a system is at risk, accurate assessment requires knowing the magnitude of the problem. Through working with CENR and EMAP programs and taking full advantage of existing and on-going long-term monitoring programs at long-term ecological research and index sites, for example, the ORD program needs to generate maps and empirical algorithms for identifying the types and locations of terrestrial and aquatic ecosystems that are most susceptible to nitrogen pollution effects. ORD needs to determine if high-risk systems can be identified using remote sensing techniques. The evidence to date suggests that higher elevation Appalachian forests, lakes, and low-order streams are most at risk. However, there is growing evidence that atmospheric nitrogen is a significant and growing source of coastal eutrophication problems, including low dissolved oxygen and changes in community structure. Research is needed to provide better estimates of the fraction of nitrogen entering streams, rivers, and estuaries that is derived from atmospheric sources and to identify geographic patterns of nitrogen overenrichment problems.

(3) Which ecosystems or landscape components are at greatest risk from nitrogen overenrichment?

A great deal of information about nitrogen sources, sinks, transformations, and effects has been generated by government and academic research over the past two decades. Before setting out to collect new data (and without minimizing the likelihood of problems in sampling bias, methods comparability, and quality assurance), a concerted effort is needed to collect, synthesize, map, and analyze existing data on nitrogen-loading rates and associated ecological effects. Given the high nitrogen loads that many of the nation's watersheds currently experience and the wealth of anecdotal evidence that nitrogen enrichment is a significant stressor in certain areas of the country, an empirical, comparative ecosystems approach should provide an efficient way to qualitatively identify the characteristics of watersheds or ecosystems displaying responses to nitrogen stress. The product of this effort will assist in the development of future monitoring and indicator development work.

(4) What factors control the assimilative capacity of terrestrial and aquatic systems with respect to nitrogen loads?

Central to the issue of nitrogen emissions are questions concerning the capacity of terrestrial and aquatic systems to process or "absorb" additional nitrogen inputs without harmful effects. Research is needed that will provide insights into the chemical, biological, and geochemical processes that determine how ecosystems respond to increases or decreases in nitrogen loads. This work needs to focus on identifying the points along a dose-response continuum at which the system "changes state," that is, exhibits a demonstrable shift in biotic structure or ecological function (e.g., increases or decreases in productivity or nutrient remineralization rates). The current debates over controls of nitrogen saturation in forests, interactions between the acidifying effects of nitrogen and sulfur compounds, and the potential role of atmospheric nitrogen in the eutrophication of estuaries are examples of issues that need to be addressed to assess the ecological risks posed by atmospheric sources of nitrogen. Examples of questions that need to be resolved include the following:

- What factors contribute to nitrogen saturation in watersheds?
- How are thresholds for nitrogen saturation linked to land use and land cover?
- How does the timing of nitrogen inputs affect ecosystem response?
- What factors control the rate of response to nitrogen inputs?

(5) How are terrestrial systems likely to change as a consequence of changing nitrogen and sulfur loads?

It is important to be able to make informed predictions about the nature and direction of ecological change when nitrogen loading rates increase or decrease. In addition to identifying harmful effects of increasing nitrogen loads, it is of equal (or perhaps even greater) value to be able to demonstrate the likely outcomes of reductions of nitrogen emissions. Thus, an important output of ORD's research on anthropogenic nitrogen that ties directly to the policy-level needs of the Air and Water Program Offices is the development of watershed-level simulation models that can be used for scenario analyses, as well as the identification of key areas of scientific uncertainty; the assistance in the generation of hypotheses; and, eventually, the guidance of management decisions.

4.6.2.5.3 Implementation

The primary focus of in-house research will be related to

- collecting, synthesizing, analyzing, and mapping existing data to develop inventories and budgets for nitrogen emissions and loading rates to the atmospheric, terrestrial, and aquatic reservoirs;
- determining the types of watersheds, landscape components, and ecosystems that are most susceptible to the effects of nitrogen overenrichment effects;
- developing indicators of nutrient overenrichment; and
- developing simulation models.

The extramural component of the program will focus on using existing microcosm, mesocosm, and field enclosure capabilities at various academic institutions to develop system-level dose-response relationships for nitrogen, to explore factor interactions, and to continue simulation model development. The extramural effort also will be needed to carry out field studies in conjunction with regional monitoring of nitrogen emissions, deposition, and effects and intensive data collection at index sites.

4.6.2.6 Regional Risk Assessment

Government Performance and Results Act Subobjective:
EPA will increase the number of places and quantify the tangible and sustainable environmental results through a collaborative, community-based environmental protection approach.

4.6.2.6.1 Statement of the Problem

Effective planning is needed to balance conservation and development so that the environment continues to support biodiversity, sustainable production of goods and services, human health, and the quality of life. An important first step is identifying the greatest threats to ecosystems, to ensure that efforts to protect or restore them are both effective and efficient. In a landmark 1990 report, EPA's SAB recommended that EPA prioritize its environmental protection efforts using the risk assessment paradigm and noted that the fragmented approach used in the past to control individual pollutants in single media was not likely to be as successful in the future, as problems become more complex and less obvious. This is particularly true for complex regional ecosystems, where the law of unintended consequences tends to prevail. Although regional risks from individual stressors (e.g., acid rain) or to individual receptors (e.g., the spotted owl) have been assessed in the past, *value-based* regional risk assessments, which compare the relative risks of multiple stressors acting on a wide range of receptors, challenge the cutting edge of ecological science.

4.6.2.6.2 Critical Questions for ORD Research

- What are the most effective ways to identify and describe the current distributions of stressors (both natural and anthropogenic) and receptors in a region?
- What are the most appropriate models to quantify the relationships between exposure and effects for potentially important stressor/receptor pairs?
- How are available data on stressor and receptor distributions (e.g., remote sensing, source monitoring, fixed site networks, county-wide surveys) best extrapolated or interpolated to estimate exposures (juxtaposition of the stressor and receptor in time and space) at scales appropriate for the exposure/effects models?
- How do regional risk assessments best deal with cascades of exposure/effects phenomena (e.g., the impacts of single-species toxicology on the guild structure of aquatic communities or the cumulative basin- wide effects of local habitat alteration on the regional population of a threatened native species)?
- How can self-consistent, future regional exposure scenarios be constructed, taking into account likely linkages among social and economic changes in a region, so as to avoid unrealistic, "all-other-things-being-equal" assessments?
- How can ecological outcomes best be linked to human uses and values in integrated loops, rather than simply as unidirectional effects of human activity?

4.6.2.6.3 Implementation

A pilot project, Regional Vulnerability Assessment (ReVA), is being conducted jointly with EPA Region III and EMAP as part of MAIA. The 162,000 square-mile study area includes all of Pennsylvania, Maryland, West Virginia, and Virginia, and parts of North Carolina, Delaware, New York, and New Jersey. Although the results of the study will address directly many of Region III's needs, one of the critical outcomes of the project is improved guidelines for future assessments and identification of critical information gaps. In 2001, the results of the pilot study will be used to develop new value-based risk assessment guidelines and a 5-year follow-up research plan identifying critical gaps in exposure data and exposure/effects models.

The pilot project will be conducted primarily in-house, with the cooperation of Region III personnel and other state and federal agencies participating in MAIA. Building on efforts to develop computerized landscape coverage of the region, evaluate indicators of ecological condition, and develop a multitiered hierarchical linkage of data from different monitoring designs, ReVA will develop computer models that juxtapose current and projected future physical, chemical, and biological stressor patterns; the geographic distribution of vulnerable receptors; and mathematical models that link the resulting exposures to direct and indirect effects on critical ecosystem structures and functions. The first step is to develop stressor and exposure profiles; the second to identify appropriate exposure/response models; and the third is to apply transport, transformation, and fate models or statistical models to simulate the resulting ecological exposures at time and space scales appropriate to available models that link exposures to effects.

In 1998, a competitive extramural grant solicitation will focus on identifying and evaluating techniques for handling scale problems and event cascades, the results of which will be incorporated into the 2001 assessment. In 1999, a grant solicitation on developing future scenarios that are internally consistent and include social and economic feedbacks in regional risk assessments will lead to a 2002 summary report.

4.6.2.6.4 Government Performance and Results Act Milestones

Although EPA's regional office client does not have its own unique GPRA objectives, regional ecological risk assessment is directly responsive to several program office GPRA objectives that actually are realized through the regions, particularly those that rely on place-based approaches such as the Office of Water's watershed-based management and critical loads efforts, and the Office of Policy, Planning, and Evaluation's (OPPE's) community-based environmental protection approach.

Specific milestones include

- **By 2000**, exposure profiles, in ARC/INFO format, of the distribution of major stressors and exposures in the Mid-Atlantic region of the United States, including ozone, acid deposition, acid mine drainage, UV-B, nitrogen, sedimentation, pesticides, and others.
- **By 2000**, receptor profiles, in ARC/INFO format, describing the condition and distribution of major receptors in the Mid-Atlantic region of the United States, including small streams, estuaries, forests, and others.
- **By 2001**, report on the pilot regional risk assessment estimating the relative vulnerability of forests and small streams in the Mid-Atlantic study region to multiple stressors, including habitat change, acid deposition, mine drainage, climate change, ozone, pesticides, and eutrophication.
- **By 2001**, recommendations for improving regional risk assessment guidelines, including enhancement of collaborative, community-based approaches.
- **By 2002**, develop a regional risk assessment research plan.

SECTION 5

Planning and Management

The goals of the planning and management process will be to maintain ORD core capabilities and to ensure that these capabilities are applied to projects that meet both ORD's Ecological Research Program goals and the highest priority needs of the regions and program offices.

5.1 Introduction

In the last few years, both the capability and capacity of the laboratories and centers within ORD have declined as resources available directly to the laboratories and centers have shifted to grants. While the capability and capacity for the in-house program has changed only slightly, the ability to expand the capability and capacity by purchasing it through contracts has decreased significantly in the new organization. As a result, the Ecological Research Program has made a strategic decision to focus the in-house program on a limited number of research areas where it has the opportunity to be a scientific leader. These areas of primary interest are presented in Section 3.

The challenge for the ecological research planning process is to maintain core capability or competencies and apply them to the greatest environmental threats, to meet the needs of the clients, and to continue to maintain a focus on future environmental issues that have yet become immediate threats or client concerns. To this end, the first step in the process has been to focus on a common goal for the core Ecological Research Program. That is, the core program will be designed to

> *"measure, model, maintain and/or restore ecosystem sustainability at multiple scales, as influenced by multiple stressors acting alone and in combination, and with consideration of both multiple receptors and endpoints."*

Consequently, ORD ideally will undertake those projects that meet the following criteria:

- the project is related to improving the ability to measure and model ecosystem sustainability,
- the project reduces uncertainty in a high-priority environmental problem area,
- the project is consistent with a short- or long-term need of the client office, and
- the project allows ORD to maintain a focused core competency and to focus on future needs.

Not everything that needs to be done will fit the planning paradigm described above. Those research projects that are consistent with ORD's unique capabilities but do not meet all of the above criteria will be considered "special projects". The fewer of such projects, the stronger the research program is expected to be. This overall concept might best be understood diagrammatically as shown in Figure 5-1. For the planning process to be successful, ORD and the client offices will need to seek areas of common interest.

Because much of the research needed by program will come from those outside of ORD, the program will maintain a close interaction with both the grants program and those outside of EPA who are interested in similar research. This will be done by contributing suggestions for grants topics and active participation in interagency research groups like CENR.

5.2 Coordination and Management

The research program is organized considering the need for core research, new scientific challenges, new research emphases, and program office needs (Table 5.1). In addition, there are several opportunities

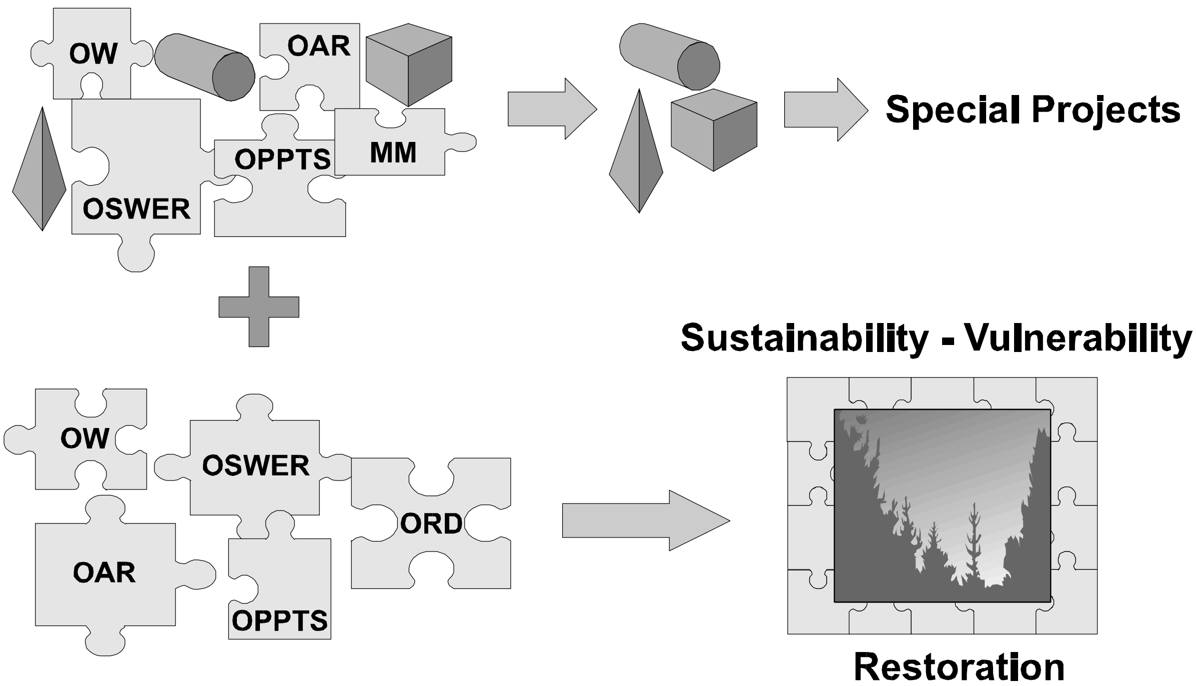

Figure 5-1. Ecological Research Program planning strategy.

for coordination across laboratories and centers in the Ecological Research Program; these include common interests in geographic locations; in specific hazards, as discussed in Section 4; and in research programs.

Common locational interests—As EPA has moved more toward distributed, flexible environmental management approaches (Section 1), there have been greatly increased opportunities to do "community-based" research and assessment. EPA's community-based ecosystem protection approach has three objectives

(1) a geographic focus that encourages a more comprehensive/holistic approach to environmental protection,
(2) focus on environmental results that is made easier by geographic boundaries of interest to the stakeholders, and
(3) partnerships and stakeholder involvement that forge unified support for environmental objectives in a defined area.

ORD's Ecological Research Program will contribute to this approach through the development of spatially related databases, new ecological indicators, innovative technologies for risk management, methods to quantify and communicate risk, and assistance with providing a sound science foundation for local decision making.

High-priority areas of interest to ORD, that will change with time, currently include the Pacific Northwest, the Great Lakes, the Gulf of Mexico, and South Florida. ORD has multiple divisions involved in each of these research areas. A lead division normally is involved in the research at these sites, and others participate as the expertise exists and the opportunity to do so arises. In addition, the Ecological Research Program has chosen the Mid-Atlantic region as a single, primary area of cross-laboratory/center/interagency coordination (see below). The research plan for this area will be developed as a cross-laboratory/center project.

Table 5-1. Elements to be considered in the development of the Ecological Research Program.

Core Research Area	New Scientific Challenges	Emerging Research Emphases	High-Priority Ecological Issues	Common Interests Across Laboratories and Centers
Monitoring and Monitoring Research	Multiple Stressors	Indicator Development Monitoring	Tropospheric Ozone	Common Locations
			Acid Deposition	
		Design	Eco-criteria and Contaminated Sediments	
Processes and Modeling Research	Multiple Receptors and Endpoints	Coupling and Scaling of Exposure and Effects Models	Wet Weather Flow	
			Contaminated Sites—Soil/ Vadose Zone	Special Environmental Hazards
Risk Assessment Research		Place Based Risk Methods	Emissions from Waste Combustion Facilities	
	Multiple Media	Watershed Risk Management	Global Change Research	
Risk Management and Risk Restoration Research			UV-B	
			Endocrine Disruptors	
	Multiple Scales	Ecosystem Adaptation and Restoration	Exotic Species	Common Programs
			Anthropogenic Nitrogen	
			Regional Risk Assessment	

- **Special environmental hazards of interest**—These have been discussed in Section 4 and represent the primary commitment within the research program. These problems offer unique opportunities for interactions and coordination because very specific sets of questions must be answered.
- **Research programs of common interest**—There are also programs that develop within EPA and ORD through numerous mechanisms. This document has not focused on these elements because they are often more budgetarily than scientifically relevant. These programs (see examples below) are a mix of problems, core capabilities, research interests, and disciplines.

- EMAP
- Ecosystem restoration
- Endocrine disruptors
- Contaminated sediments
- Global change
- Eco-criteria
- Non-point source pollution
- Wetlands
- High-performance computing
- Advance monitoring initiative

The facts that they are volatile budgetarily and represent such a mix of research limit their utility as a science organizing hierarchy. They do, however, exist and have requirements for multiple laboratory/center involvement and interaction.

To date, the linkages among investigators, laboratories, and centers often have been more fortuitous than planned. However, it is the intent of the program to improve the linkages such that collectively the goals presented can be better achieved.

Management of the program is by laboratory and center. The Associate Directors for Ecological Research work as a team, meeting four times a year to discuss current research, new directions, and common needs. The largest, most fully integrated study, a test for the joint planning process and the research goals, will be in the Mid-Atlantic region.

5.3 The Mid-Atlantic Integrated Assessment

Among the challenges facing ORD's ecological program is the demonstration that its research does in fact provide the scientific underpinnings for ecological risk assessments and relevant risk management decisions. This challenge suggests that a test of ORD's program is to select a region of the country, conduct the monitoring and modeling activities necessary, produce a regional comparative risk assessment, and engage the regional managers in relevant risk management decisions. The Mid-Atlantic region of the United States has been chosen by ORD for this purpose. It encompasses the states within EPA Region III (Delaware, Maryland, Pennsylvania, Virginia, and West Virginia) and portions of New York, New Jersey, and North Carolina necessary to provide coverage of the entire Chesapeake Bay, Delaware Bay, and Albemarle-Pamlico Sound watersheds. Region III and the encompassed states have been progressive in their application of comparative risk assessments in decision making and in improvements to their approaches for monitoring and managing the environment and provide eager partners in this endeavor. Early EMAP studies in ORD are extensive monitoring coverage and assessments for terrestrial and aquatic systems and landscapes and, thus, a rich data source for assessment. The added focus of ORD's regional vulnerability activities, risk management research, and ecological assessments will significantly expand these efforts. Additionally, the mid-Atlantic region has become the pilot area for the CENR federal monitoring framework.

EPA managers in the Mid-Atlantic region have adopted a comparative risk perspective for setting their priorities. To enhance their ability to effectively embrace comparative risk assessments, they are willing to try improved approaches to monitoring, including new designs and real indicators of environmental progress, which will lead to geographic targeting and prioritization of problems. There is also clearly an interest in enhancing the capability of modeling exposure to stressors and predicting alternative futures under multiple management scenarios. These interests and needs are consistent with the strategic direction of ORD's ecological research and provide fertile ground for testing the applicability of results.

ORD will bring to bear the best of its research from NERL, NHEERL, and NRMRL, as well as the work at NCEA and the grants awarded under NCERQA. The intended outcome of ORD's research is as follows:

- improved monitoring and assessment of the conditions of estuaries, streams/rivers, wetlands, and landscapes within the Mid-Atlantic region and analysis of the relative magnitude of existing stressors;

- modeling of stressor profiles across the region juxtaposed with the presence of potential receptors to evaluate the relative vulnerability in the region to the prevailing stressors;
- predictive modeling of alternative futures under multiple management options;
- comparative risk assessment for ecological systems within the Mid-Atlantic region; and
- priorities among risk management options.

Working across the ORD laboratories and centers and in conjunction with the EPA Region III, the states and other federal agencies, ORD's research will be subjected to the litmus tests of relevancy and applicability in real-life situations. ORD and the region have begun to plan this process to ensure that it meets the expectations of all participants.

5.4 Index Sites

ORD also must develop an improved understanding of ecological resource response to exposure and methods to monitor changes in those same systems. To facilitate interaction across laboratories and centers, two types of research sites have become field laboratories to conduct joint research: (1) the EMAP sites and (2) the developing network of "near-ORD-laboratory sites".

5.4.1 EMAP Index Sites

In cooperation with the National Park Service, 13 sites have been chosen as cooperative research sites.

(1) Big Bend National Park, TX—arid and multiple elevations
(2) Everglades National Park, FL—tropical wetlands and lagoon coral reefs
(3) Virgin Islands National Park, VI—coral reefs, tropical estuaries, and tropical forests
(4) Sequoia National Park, CA—multiple-elevation forests and unique species
(5) Rocky Mountain National Park, CO—high-elevation forests and lakes
(6) Smoky Mountains National Park, NC—multiple-elevation forests, lakes, and streams
(7) Shenandoah National Park, VA—multiple elevation forests, lakes, and streams
(8) Acadia National Park, ME—rocky fjord estuaries and northeastern coastlines
(9) Denali National Park, AK—arctic ecosystems, high-elevation forests, glaciers, and tundra
(10) Olympic National Park, WA—Pacific Northwest, humid ecosystems, multiple-elevation forests and streams
(11) Glacier National Park, MT—high-elevation forests, lakes, and streams and glaciers
(12) Canyonlands National Park, UT—multiple elevations and arid ecosystems
(13) Theodore Roosevelt National Park, ND—grasslands

Currently, significant air quality monitoring is being conducted at these sites, and additional air quality monitoring activities are being initiated to standardize the measurements being taken at each site, including the measurement of UV-B exposure at all sites. In addition, a solicitation for research to be conducted at these sites will be issued in the summer of 1997, focusing on the effects of UV-B, ozone, and nitrogen deposition on park ecosystems. Monitoring for other media and additional monitoring to be done at these sites is being determined.

It is envisioned that in-house efforts will include screening of chemical toxicants in air, soil, water, and biota; development of new methods to characterize landscapes at these sites; research to better understand the cause and effect relationships among acid deposition, nutrification, UV-B, and other regional-scale environmental hazards; and improving the understanding of ecosystems.

5.4.2 Near-Laboratory Sites

When possible, development and testing of exposure methods and tools will be done at near-laboratory sites. These sites will serve as the local field laboratories. The expertise of the local divisions will determine the type of research to be conducted. However, there will be some common studies developed across all sites that will require the expertise of the entire laboratory and, in some instances, other laboratories as well.

Below is a brief summary of each of the four sites chosen to date.

5.4.2.1 Savannah River Watershed

This site is located near the Ecosystems Research Division in Athens, GA. Current research focuses on efforts to

- characterize the Savannah River basin: identify and compile existing databases of major point sources, probable non-point sources, weather, soil, stream flow, water quality, and land use; develop a basin map with watershed boundaries and delineations of hydrologic unit areas, a digitized soils map, and a contour elevation map; and develop data representing model input parameters;
- identify potentially vulnerable ecosystems, effects, and related activities, including surface water, groundwater, logged areas, fishing, stream shade reduction, recreation, sewage discharge, septic tanks, farms (row crops, forests, and pastures), animal production, and industrial and municipal discharges;
- develop a map of basin characteristics to reflect land use changes over time and location of all known and suspected point sources and wet and dry deposition measurements;
- develop, design, and a conduct field study to evaluate the extent and distribution of vulnerable ecosystems resulting from chemical and nonchemical stressors; and
- conduct ecological model development and testing on both watershed and basin scales for use in conducting reliable regional vulnerability assessments.

5.4.2.2 Neuse River Watershed

This research will be conducted near the ORD Research Triangle Park, NC, facilities to support four primary research objectives:

(1) develop and validate atmospheric methods and instruments,
(2) provide ambient concentration and deposition data for the local watershed,
(3) conduct ecological exposure research for the local watershed, and
(4) support ambient/ecological measurement needs for the near-laboratory research program.

The primary research initiatives for the ecological near-laboratory site will focus on developing, integrating, and validating new broad-based, low-resource-requiring tools (e.g., monitoring/analytical methodologies, model development, and other assessment techniques) to characterize the commonalities and influences of stressors at all index sites. Of particular interest at this site are atmospheric measurements and endocrine disruptors associated with animal farming.

5.4.2.3 Lower Colorado River Watershed

This site is located near the Characterization Research Division in Las Vegas, NV. The focus of research at this site will be to

- determine the feasibility of applying a multiscale landscape assessment approach in conducting a comparative vulnerability assessment of the Lower Colorado watersheds (long-term);
- determine the feasibility of applying a multiscale landscape assessment approach to project vulnerability of selected ecological resources, given projected changes in landscape pattern, including field verification;
- determine gaps in the current state of science in conducting regional vulnerability assessments; and
- develop watershed-scale models to predict future landscape change scenarios and associated impacts.

5.4.2.4 Little Miami River Watershed

The focus of research at this site will be to develop suites of indicators for measuring and diagnosing the sources of exposure resulting from human use of the watershed from farming practices, development, and industry and to examine restoration techniques to manage past changes and those that may occur in the future.

5.5 Information Management: The Inverse of the Tragedy of the Commons

5.5.1 Introduction

From a research perspective, there are a six grand challenges facing ecologists in dealing with environmental issues at the regional and global scales addressed in this strategy. These are

"(1) developing non-experimental methods to conduct large-scale research; (2) incorporating information from new data sources and other disciplines; (3) standardizing and controlling the quality of data; (4) developing new statistical tools; (5) integrating, synthesizing and modeling knowledge about ecological systems; and (6) incorporating humans and their activities explicitly into ecological studies" (Brown, 1994). Broadly viewed, these challenges can be considered requirements that will influence significantly the development of ORD environmental information management systems needed to successfully implement the ecological strategy.

Historically, most environmental analyses have been small in spatial scale, relatively short in duration, and performed by small collocated team of investigators. Consequently, the practice of environmental information management has been geared largely to provide databases and systems commensurate with this scope of activity. However, as evinced in this strategy, the discipline of environmental science is changing. Issues of increased scale, availability of large volumes of remotely sensed data augmenting the overwhelming volume of data from traditional sources, inadequacy of commercially available software packages designed to handle these types of data, and an increased emphasis on multiple investigator research, requiring shared access to data, are driving changes in the way environmental information is managed.

To meet these challenges, ORD will need to leverage technology and modify long-accepted management and cultural paradigms that impede the sharing of data, information, and software. An enlightened information management perspective is antithetical to what Hardin suggests in "The Tragedy of the Commons". Although advantages accrued by villagers grazing their sheep in a common area eventually decrease through degradation of the resource until benefits are lost to all, management of environmental information presents the inverse. If properly managed, benefits that accrue to individual contributors to a common pool of ecological data and information continue to grow as the amount of information increases. The common resource is enhanced, not diminished, by each additional increment of participation.

This ecological information management strategy is predicated on the following fundamental principles:

- understanding the information management requirements of ORD scientists engaged in environmental assessment and analysis;
- identifying, developing, testing, and then promulgating sound information management policies, standards, and procedures for data, metadata, and systems;
- providing the technical and personnel infrastructure to support the development and operations of systems and databases that satisfy the needs of ORD scientists and collaborators; and
- leveraging EPA, federal, state, and other information management resources to accomplish the objectives of the ecological strategy.

As an overarching principle, the ecological information resources management (IRM) strategy will seek out and take advantage of information management capability, work, and systems that already exist or are underway throughout ORD and other parts of EPA.

5.5.2 General IRM Requirements To Support Ecological Assessment

Figure 2-1, presented in this document, provides insight on information flow and the mapping of IRM-related functions among NCEA, NHEERL, and NERL. The concept that underlies the mapping is that NHEERL and NERL are primary generators and users of scientific data and information. The role of NCEA is as a secondary user of information generated in other parts of the organization and from other sources. The idea of primary versus secondary user is, however, not hard and fast. In many cases, NHEERL will be a secondary user of data generated by NERL and vice versa. From a strategic perspective, this indicates that it is in the best interest of each organization charged with implementing the ecological strategy to devote resources to the management of descriptive information (metadata), as well as data to support the assessment process.

Figure 5-2 maps steps in the assessment process to components of an environmental information management system (EIMS). Each of the system components is described below.

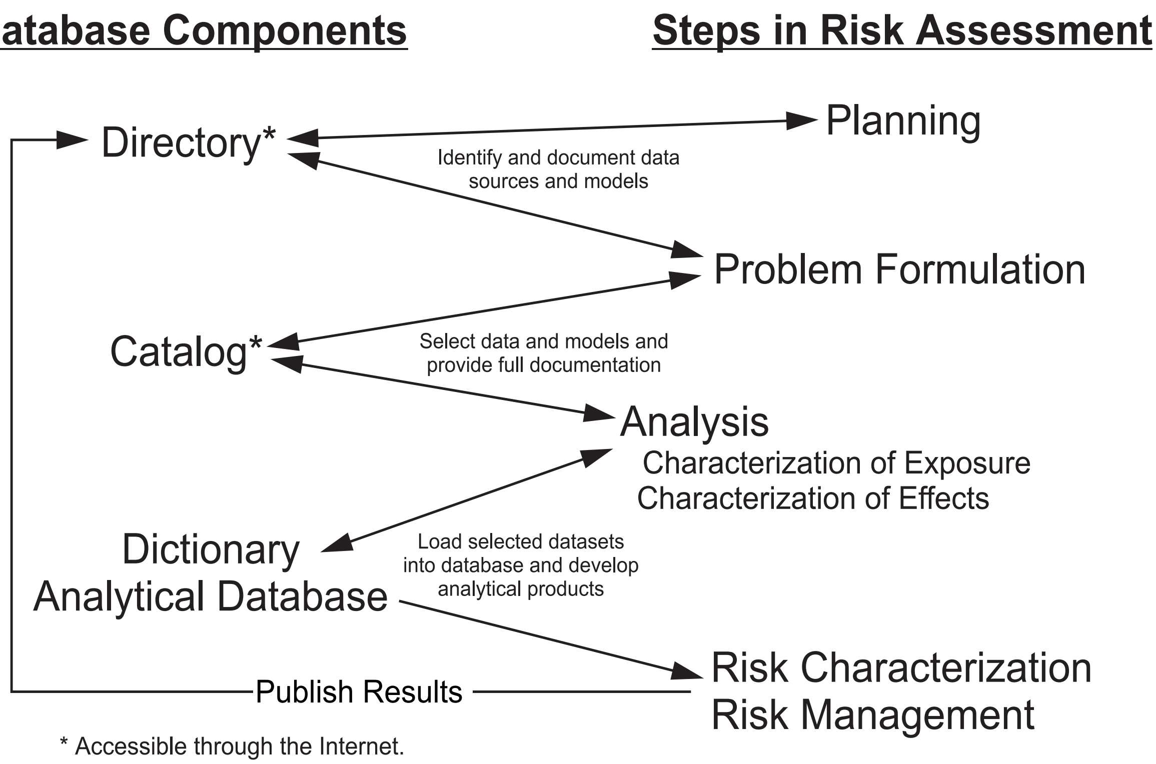

Figure 5-2. Environmental information management system.

Directory The directory is high level index that contains information about "objects" that are relevant to the assessment process. These objects include projects, documents, data sets, databases, and software tools. The types of information that the directory contains about objects include a short narrative abstract, contact information, locational information, and keywords that allow the directory to be searched in a variety of ways. The function of the directory with respect to assessment is analogous to a bibliographic search for references prior to writing a scientific paper.

Catalog The catalog contains detailed information about objects that are indexed in the directory. The level of detail is sufficient to allow an assessment scientist to make a determination of whether a particular data set, database, or tool is appropriate for his intended use of it. Examples of information in the catalog are definitions of individual attributes in a data set, information about methods used to collect and analyze the data, and quality assurance information. The catalog provides a template to guide and capture information about data that are produced during the process of evaluating data for secondary use.

Dictionary The dictionary contains specific information about each of the attributes in a data set or database. If a data set is included in the database, the dictionary is the means by which metadata in the directory and catalog are linked to the information that is included in the database structure. Examples of information in the dictionary are the format, length, definition, and method for a specific attribute.

Analytical Database The purpose of the analytical database is to facilitate the process of analyzing multiple data sets together. Initial selection of data sets for a particular assessment project is made by reviewing directory information. Data sets of interest then are evaluated using the catalog as a template. Those that are still deemed valuable in support of the assessment are loaded into the analytical component of the database. This process results in a collection of data organized in a homogeneous way, which greatly facilitates access and manipulation, using a variety of analytical tools. Examples of tools are geographic, visualization, statistical, and spreadsheet systems.

The focus of discussion has centered on information management requirements that directly support the analytical process. These are the requirements that are most directly applicable to meeting the immediate objectives of the Ecological Research Strategy. There are a plethora of additional requirements for laboratory information systems, field data recording equipment, and general data management hardware, software, and personnel infrastructure. In addition, there are ongoing projects, such as Models-3, that are essential to support and integrate into the framework that supports ecological information management. To support the objectives of the ecological strategy, each ORD laboratory and center will support these existing projects and needs. In addition, staff, resources, and a commitment to training will be required to successfully implement the IRM component of the strategy.

5.5.3 Management Approach

Ecological data will be managed as an ORD corporate resource. Use of environmental information management systems discussed in the previous section to administer the data and metadata will provide the opportunity to share data and tools throughout the organization. Managing the network of environmental information management systems will be coordinated by the science data management board (SDMB). Individuals representing each laboratory and center will interact with the chairman of the board. Following is a list of strategic level functions that will be engaged by the laboratories and centers and coordinated by SDMB.

- **Architecture planning.** Strategic information management planning for the individual laboratory or center in coordination with the SDMB to ensure that EIMSs are compatible across ORD (The major focus will be developing and promulgating consistent policies, procedures, and standards to ensure the highest integrity of ecological information products.)
- **User interaction and planning.** Interaction with users of ecological data in the laboratories and centers on a continual basis to develop and implement effective plans to meet information needs
- **Systems engineering.** Development and modification of software applications including EIMS to meet user needs
- **Systems support and operations.** Maintenance of the operating environment to support environmental information management systems
- **Science direction.** Awareness of advances in science, such as remote sensing, that may have an impact on information technology
- **Advanced technology evaluation.** Evaluation of new technology and development of migration plans to integrate useful technologies into the ecological data management mainstream

The ability of each of the participating organizations to execute these functions in a coordinated fashion is critical to meeting the objectives set forth in the ecological strategy.

5.5.4 Status of Data Management

Progress in support of a cogent strategy to manage ecological data is underway. EIMS has been developed to manage both data and metadata. It incorporates existing metadata standards, for example, those promulgated by the Federal Geographic Data Committee. The metadata in the system are easily accessible using widely available Internet browsers for both update and retrieval. Data sets and models described in the system can be downloaded easily for use on individual workstations. The actual data in the system are accessible using a wide variety of analytical tools including geographic information systems, statistics, and visualization. As described in an earlier section, EIMS supports and parallels the ecological assessment processes.

A working group consisting of representatives from NERL, NHEERL, and chaired by NCEA has overseen the implementation and evolution of the EIMS. It is well past the prototype stage of development and is currently operating in Region 10, ReVA, and NCEA. Additional "instances" of the system are being implemented to support Surf Your Watershed in the Office of Water and EMAP. NCEA currently is working with representatives from OPPE, the Office of Information Resources Management, and the Office of Water to evaluate use of the system to support an EPA-wide inventory of environmental information and tools.

The ecological associate directors of ORD have endorsed a coordinated effort to bring the data management of scientific data into a uniform system paradigm. Meetings are scheduled between NERL and NHEERL to establish an approach to storing UV-B data and linking it to EIMS for analysis. Discussions are underway that will result in selection of the most efficient approach to either merging or linking EMAP-II and the EIMS for ReVA systems to support assessment in MAIA.

The information management component of the ecological strategy builds on this foundation. It provides an opportunity to make rapid progress toward an environment where sharing data, information, and tools used in ecological assessment is not an insurmountable burden imposed on each assessment project.